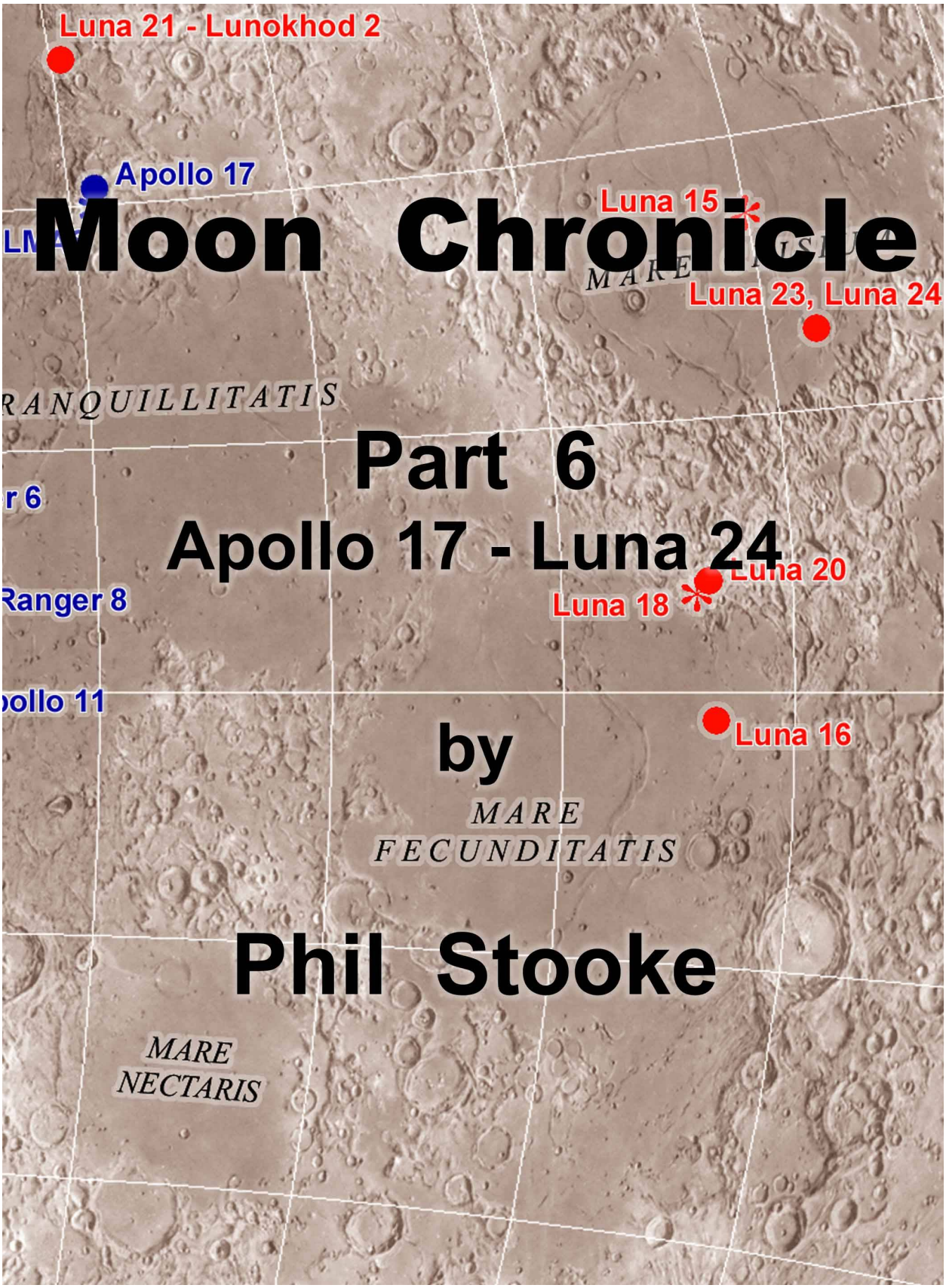

Moon Chronicle

Part 6

Apollo 17 - Luna 24

by

Phil Stooke

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Apollo 17-Luna 24

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Introduction

This volume of the Moon Chronicle brings us to the end of Apollo lunar exploration with Apollo 17, and the Soviet Union's final lunar missions of the 1970s including the Lunokhod 2 rover and the Luna 24 sample return mission. A last Apollo note, melancholy for some, was the termination of the ALSEP instrument operations in 1977. With that, lunar exploration ceased for over a decade. What followed initially was a long series of studies for future missions and exploration scenarios which partially filled the void and will be detailed in the next volume.

Apollo 17 was a fitting conclusion to the first phase of human exploration of the Moon. A spectacular landing site and audacious rover excursions showed what Apollo was capable of. It was followed by Lunokhod 2's long distance traverse which held the record for remote rover operation for 41 years, until Opportunity surpassed it in July 2014. Luma 24 brought back samples from Mare Crisium, the last lunar sample return until China's Chang'e 5 in 2020.

I have devoted many pages of the Chronicle to Apollo landing site selection and EVA planning. For this I have gleaned much from the minutes of the Apollo Site Selection Board, the Group for Lunar Exploration Planning and the Science Working Panel. I was introduced to these thick bound volumes by Fran Waranius, librarian at the Lunar and Planetary Institute (LPI), just after my first Lunar and Planetary Science Conference (LPSC) in 1987. The meeting ended at noon on Friday and I walked over the road from the Johnson Space Center to LPI, which was then housed in a fine old mansion on NASA Road 1. The place was open but deserted so I visited its library in a separate outbuilding. There I first saw these treasures as Fran told the story (as she had many times before) of how they and many maps and other resources were rescued as NASA moved on from Apollo to its next challenges. It was more than a dozen years later, with LPI in its new building at the University of Houston, Clear Lake, that I sat down with them to distill years of work into a narrative. It awakened my interest in landing site selection which I have documented ever since.

Phil Stooke
2025

Spacecraft image credits:

Apollo images: Accessed via the Apollo Lunar Surface Journal (surface Hasselblad images) and https://data.lroc.im-ldi.com/apollo/browse (orbital images).

Lunar Reconnaissance Orbiter camera (LROC) data: NASA/GSFC/Arizona State University, and Robinson, M.S., *et. al*. (2010). Lunar Reconnaissance Orbiter Camera (LROC) Instrument Overview, *Space Science Reviews*, v. 150, pp. 81-124. https://doi.org/10.1007/s11214-010-9634-2

Lunar Reconnaissance Orbiter Laser Altimeter (LOLA): Smith, D.E., Zuber, M.T., Jackson, G.B. *et al*., 2010. The Lunar Orbiter Laser Altimeter investigation on the Lunar Reconnaissance Orbiter mission. *Space Science Reviews,* v. 150, pp.209-241. https://doi.org/10.1007/s11214-009-9512-y

Lunar QuickMap (https://quickmap.lroc.im-ldi.com), developed by NASA, Arizona State University and Applied Coherent Technology Corp.

Luna: Most Luna images, maps derived from them and any other material originating from the Soviet Union were provided courtesy of V. V. Shevchenko, Director, Sternberg State Astronomical Institute, Moscow and his colleagues. These materials were not copyrighted.

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1972: Science Working Panel

The Panel met on 16 March, 10 to 11 May, 26 to 27 July, 2 to 3 October and 10 November 1972 to plan surface activities for Apollo 17. The maps shown in Figure 289 illustrate various versions of plans for the EVAs taken from the minutes of these meetings. This was the final stage of Apollo mission planning and the Panel disbanded after the last meeting. The minutes of the Panel meetings are held in the library at the Lunar and Planetary Institute in Clear Lake, Texas, south of Houston.

Figure 289A is an early plan including two alternative versions of EVA 2, one to the northwest, the other to the northeast. Both would return from Station 6 (a prominent boulder which had rolled down the hillside, leaving a track) to the LM, but a shortcut on EVA 2B which omitted Stations 5B and 6 was also possible. Black Crater in this map was later renamed Shorty (Figure 291). One stated goal was to observe the effects of LM exhaust on the landing approach path east of the landing site. Figures 289B and 289C show versions in which the northern route is shortened and a stop just for photography is added near a secondary crater structure later named Victory. Figure 289D adds several brief stops at which samples could be collected without dismounting from the rover. This was done to increase sampling options with minimal added time, making it appealing to mission planners. The Figure 289D plan was adopted for Apollo 17. Figure 290 shows the regional context of the site

23 November 1972: Fourth N-1 launch

This fourth and last launch of the Soviet Union's great N1 lunar rocket carried a test version of the hardware that was intended to carry cosmonauts to the Moon. The orbital module, 'Lunar Orbit Cabin' (LOK), was flown without a crew to test systems and operations.

A dummy 'Lunar Cabin' (LK) lander was added to give realistic mass for the tests. The stack was launched from Baikonur and was intended to enter lunar orbit for extensive testing, including the LOK returning to Earth. As with the three earlier flights (21 February 1969, 3 July 1969, 26 June 1971) the launcher failed (Lardier, 2018), this time after 107 seconds when a fire in the engine area caused a catastrophic explosion. Soviet lunar landing plans did not long survive this accident, and the nation's attention shifted towards its space station programs.

Lardier, C., 2018. The Soviet manned lunar program N1-L3. *Acta Astronautica*, v. 142, pp. 184-192. https://doi.org/10.1016/j.actaastro.2017.10.007

07 December 1972: Apollo 17

Apollo 17, the last of seven attempted lunar landings and six successful landings in the Apollo program, was launched from Pad 39A at Kennedy Space Center on a Saturn V booster at 05:33 UT (the first Apollo launch at night), 2.7 hours late due to a launch sequencer problem. The spacecraft entered a parking orbit at 05:45 UT and the translunar injection burn occurred at 08:46 UT. The CSM separated from the S-IVB at 09:15 UT and docked with the LM at 09:30 UT. The S-IVB was discarded at 10:18 UT and impacted the lunar surface at 20:33 UT on 10 December at 4.21º S, 12.31º W (Figures 291B, 292). A mid-course correction burn was made at 17:03 UT on 8 December, and on 10 December 10 the SIM bay door was ejected at 15:06 UT and Apollo 17 entered lunar orbit after a lunar orbit insertion burn beginning at 19:47 UT. About 4.4 hours later the orbit low point was dropped to 28 km.

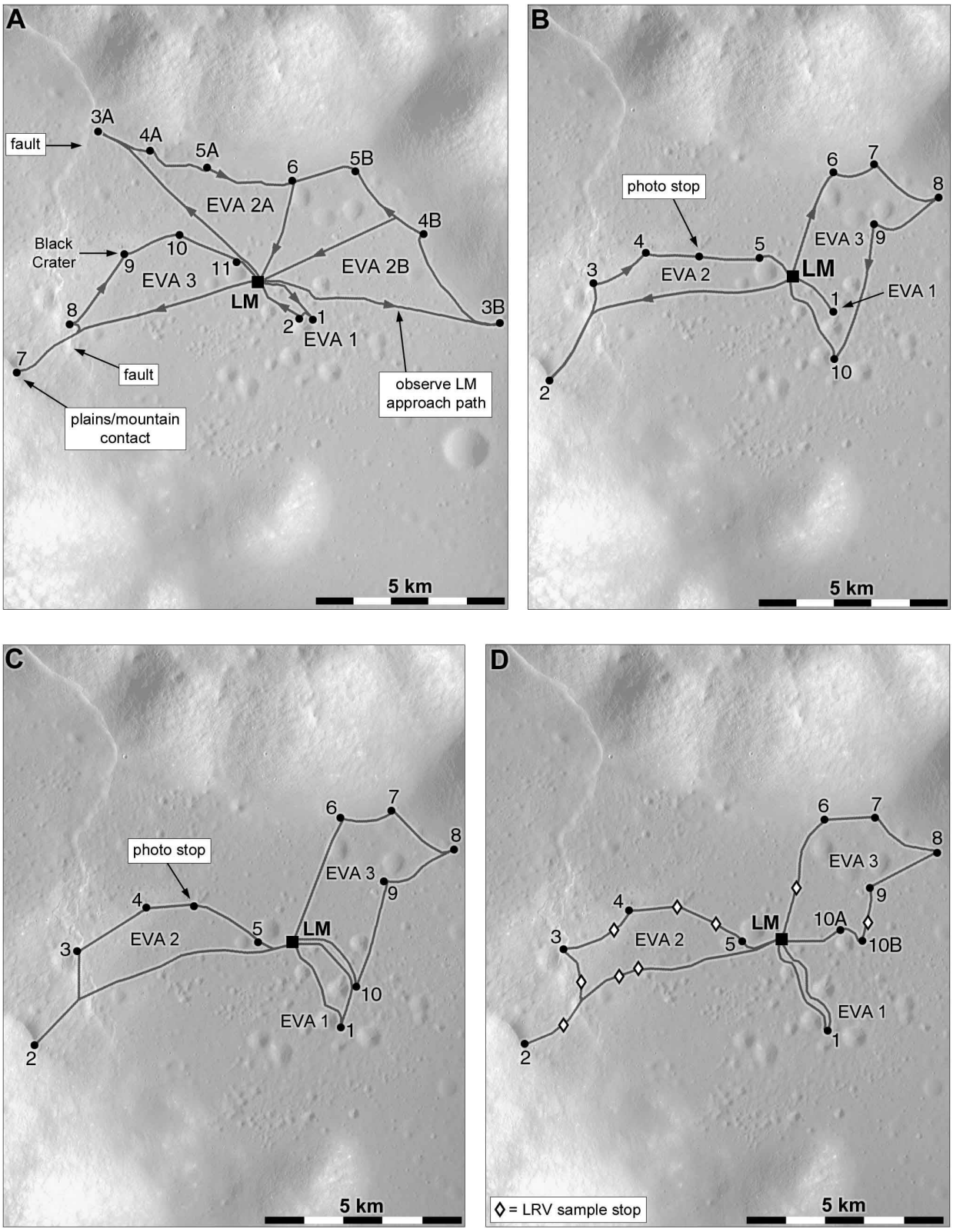


Figure 289. Apollo 17 EVA plans from the Science Working Panel. A: EVAs with emphasis on North Massif exploration, showing two alternatives for EVA 2. B, C: EVAs with a photo stop at Victory crater. D: EVA with rover sampling stops, adopted for Apollo 17.

At 14:35 UT on 11 December Commander Eugene A. Cernan and Lunar Module Pilot Harrison H. Schmitt entered the LM, leaving Command Module Pilot Ronald E. Evans in the CSM. The LM separated at 17:21 UT on 11 December and dropped its orbit low point to 11.5 km with a burn at 18:56 UT. The final descent began at 19:43 UT and the LM landed at 19:55 UT in the Taurus-Littrow valley at 20.2º N, 30.8º E. This site and the old Littrow site (Figures 113, 119, 120, 138) are shown in Figure 290A. Cernan and Schmitt made three EVAs for a total of 22.1 hours on the surface. They drove 35 km on their LRV, collected 110.5 kg of rock and soil samples, took many photographs, set up an ALSEP and performed other scientific experiments. Evans operated instruments in the SIM Bay and performed other experiments from orbit.

The LM launched from the lunar surface on 14 December at 22:55 UT, 75 hours after landing. The LM docked with the CSM on 15 December at 01:10 UT, and the samples and equipment were transferred to the CSM. The LM was jettisoned at 04:52 UT and struck the Moon at 06:50 UT at roughly 19.96º N, 30.50º E, within view of the landing site. The impact point has not been located. After a 36 hour period in lunar orbit for additional photography, the Trans-Earth Injection burn began on 16 December at 23:35 UT. Evans began a 67 minute deep space EVA on 17 December at 20:27 UT, making three trips to the SIM bay to collect film from the cameras and the lunar sounder experiment. The CM and SM separated on 19 December at 18:57 UT, and Apollo 17 splashed down at 19:25 UT after a mission elapsed time of 301 hrs, 52 minutes. The splashdown point was in the Pacific Ocean at 17º 53' S, 166º 7' W, 600 km southeast of Samoa and 6.5 km from the recovery ship USS Ticonderoga.

Navy Captain Cernan had flown on Gemini 9 and Apollo 10 before this flight. Navy Commander Evans and USGS geologist Schmitt, the only professional scientist to fly to the Moon, were making their first spaceflights. The Apollo 17 backup crew consisted of John Young (Commander), Stuart Roosa (Command Module Pilot), and Charles Duke (Lunar Module Pilot). Young and Duke had flown on Apollo 16 and Roosa on Apollo 14. Originally the crew of Apollo 15 would have been the backup crew for Apollo 17 but the postage stamp problem made that assignment impossible. The Apollo 17 CM was called America, and the LM was called Challenger.The Apollo 17 Command Module is now on display in Space Center Houston, adjacent to the Johnson Space Center, Houston, Texas.

Figure 290A shows the area surrounding the Apollo 17 landing site. It takes its name from the Taurus Mountains on the rim of Mare Serenitatis and the old crater Littrow north of the landing site. The old Littrow site was about 70 km northwest of this new site. Figure 290B shows the Taurus-Littrow Valley with the names of major features and the location of Figure 257. Family Mountain was a name on the pre-mission maps. 'West Family Mountain', visible from the landing site, was mistaken for Family Mountain by the astronauts on the surface. This event is described in detail in the Apollo Lunar Surface Journal.

Figure 291A shows many more informal names assigned to features at the Apollo 17 landing site. This map is based on Figure 5-3 of NASA (1973), and shows the names chosen by the crew prior to the mission. A few additional names in the crowded central area are shown on the individual EVA maps. Several of these names were modified just before and after the flight. The names San Luis Rey and Mariner were transferred to smaller craters near the landing site before the final EVA planning maps were drawn. Bowen, Mackin, Hess, Steno and Nansen are now officially designated with a suffix '-Apollo' (*e. g.* Mackin-Apollo) to distinguish them from craters elsewhere on the Moon with the same names. Two craters were named with initials: MOCR after the Mission Operations Control Room, from which Apollo flights were directed; SWP after the Science Working Panel who helped draw up the mission plans. After the mission SWP was renamed Bowen-Apollo. The names Lee and Lincoln as sections of the scarp were combined as shown in Figure 264A.

Lunar and planetary surface features are assigned names by the International Astronomical Union. Their Working Group for Planetary System Nomenclature proposes names based on approved categories, primarily astronomers and others associated with lunar studies in the case of large lunar craters and personal first names from around the world for smaller craters. This official process has often been in conflict with the needs and wishes of people involved in exploration who wanted to apply names for features at landing sites. Names of many features near Apollo landing sites, including most of those on this page, were unofficial at the time, but many were adopted by the IAU in 1973 under the category 'Astronaut-named features'. Even unofficial names have historical significance and so are recorded here wherever possible.

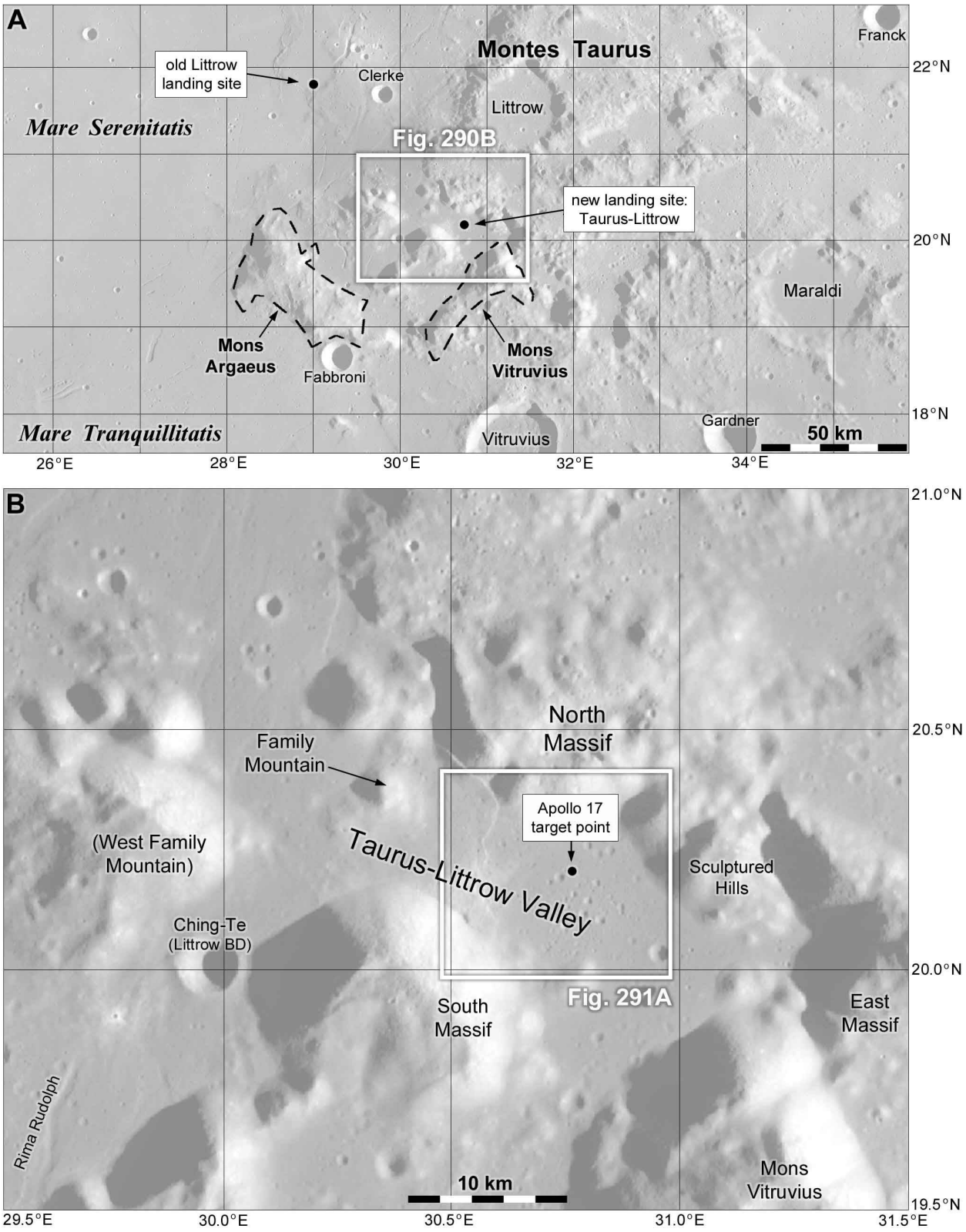


Figure 290: Apollo 17 landing area. A: The landing region showing the old Littrow site. B: the Taurus-Littrow Valley and surrounding mountains.

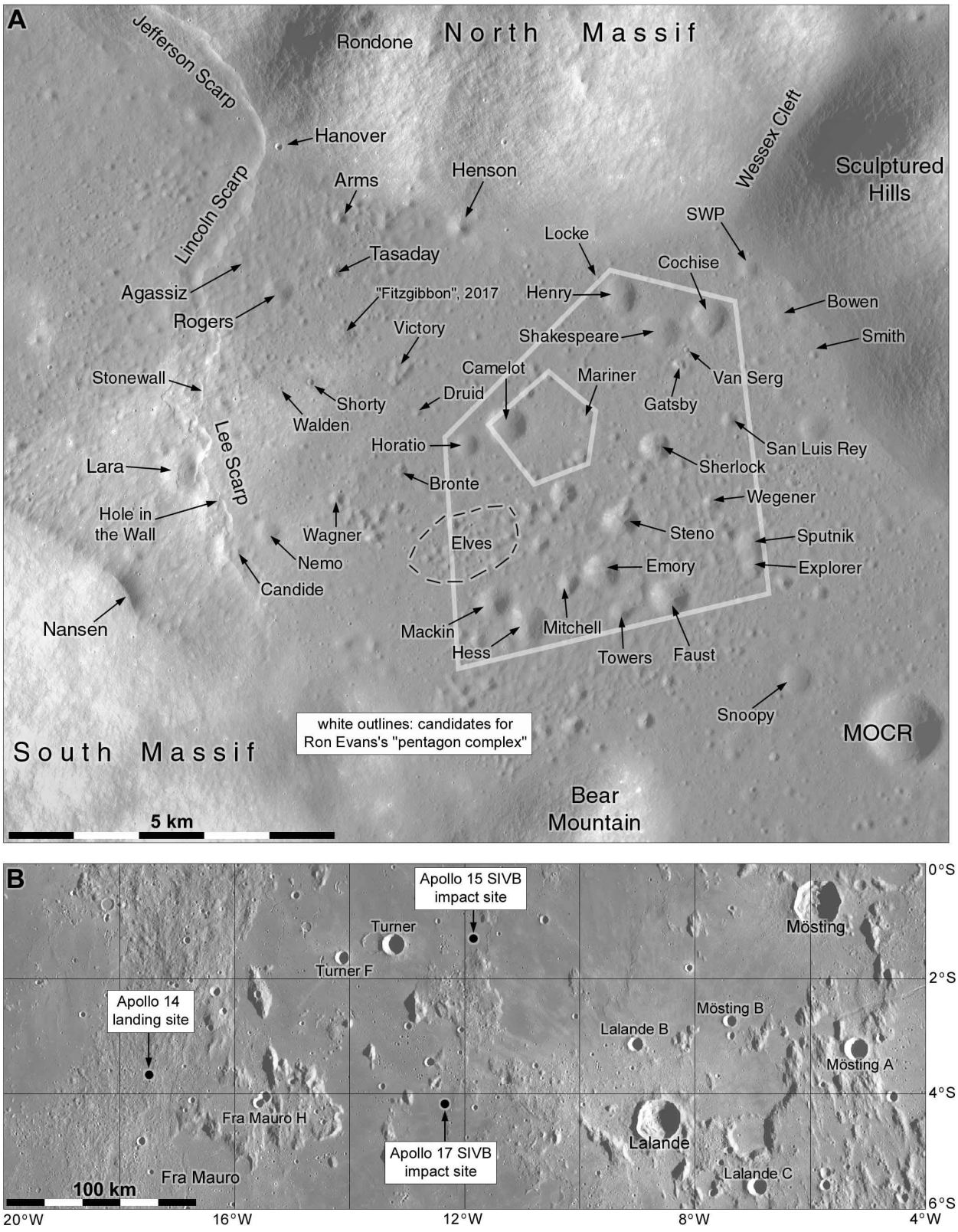


Figure 291: Apollo 17. A: Names of features at the Apollo 17 landing site. Mariner and San Luis Rey were changed just before the mission, Several other names were changed after the mission. B: Apollo 17 SIVB impact location.

The Apollo 17 SIVB was crashed to provide a seismic signal for the four working seismometers already established on the Moon. The impact was targeted for 7.0º S, 8.0º W, northwest of the large crater Ptolemaeus (Figure 225C in Chronicle Section 5). Impact was expected within about 500 km of that point. Tracking suggested an impact at 4.2º S, 12.3º W, about 160 km northwest of the target (NASA 1972a, 1972c), close to the Surveyor 2 impact area. The impact occurred in a ray-covered mare area just west of the 5 km diameter crater Turner M, and it was eventually found in LRO images (Wagner *et al*., 2017). Figure 291B shows the region around the Apollo 17 SIVB upper stage impact, and Figure 292 locates the impact crater.

Figure 293 locates the Apollo 17 landing site. Several alternative EVA plans were developed to accommodate potential problems during the mission (Figure 260). Figure 294 is based on NASA graphics from the Science Working Panel minutes for the meeting of 16 November 1972 (identified in the caption to Figure 294), and scanned documents available through the Apollo Lunar Surface Journal website.

Figure 294A shows restricted EVAs to be followed if a damaged rover could only carry one astronaut. Figure 294B was a walking EVA plan in the event that the rover could not be used at all, including two alternative plans for EVA 3. The astronauts would carry the Traverse Gravimeter Experiment on EVA 2 and take measurements at four locations, providing a gravity profile across the valley floor. They would carry explosive charges for the Active Seismic Experiment and deploy them at two locations on each EVA. Figure 294C shows revised EVAs for a landing 2.7 km north of the target (the maximum expected offset). South Massif would not be visited at all in this case. Figure 294D would apply if the LM landed 2.7 km south of its target and would be able to reach both North Massif and South Massif.

The station numbers used in these EVAs were the same as on the mission plan shown in Figure 289D, to avoid confusion. Where a site was moved slightly it was designated with a letter (*e.g*. 5A, 10B). Station 1 in the EVA plan was moved during the mission and the new site was sometimes called Station 1A to fit this scheme. 'Alt.' identifies alternative locations along the scarp for Station 3 and the alternative version of EVA 3 on the walking mission. Walking mission stations were different enough that they were assigned letters instead of numbers.

SWP versions of Figures 294A and 294B had other minor variations. For Figure 294A an additional station labelled '3/4' was inserted between stations 3 and 4 on EVA 3. Their version of Figure 294B, EVA 3 (alternate) took the crew out to the Victory crater photo stop, then back to Station F (located where Station G is shown in Figure 294B), and then to a new Station G on the south rim of Camelot where the explosive charge is indicated here.

The Apollo 17 landing area, including the LM, ALSEP and the Surface Electrical Properties (SEP) site, is portrayed in Figure 295, with the locations of photographic panoramas (black circles), collected rock and soil samples ('S'), and items of deployed equipment. EP-2 and EP-3 are the explosive charges (EP = 'explosive package') deployed for the seismic experiment. They were detonated by command from Earth after the astronauts left the surface. Figure 295 includes information from Figure 6-98 of Muehlberger *et al*. (1973), LRO images and surface panoramas.

Figure 296A shows the landing site and EVA routes drawn on an LROC NAC mosaic base. The actual LM location and route are shown in black. The route mapped on the DMA (1975) map is shown in white and the modified version from Stooke (2007) is drawn as a gray line. Later maps of individual EVAs show the route planned before the mission.

Cernan landed the LM about 300 m northeast of the target point (Figure 297), just north of a crater named Poppie (incorrectly shown as 'Poppy' on most contemporary maps; it was named for Cernan's father, called Poppie by Cernan's daughter. The name Poppy is sometimes said to commemorate Frances Northcutt, nicknamed Poppy, who was a NASA engineer during Apollo and one of the first women to work inb Mission Control, but this commemoration is not documented).

Details of the mission plans and initial results were presented by MSC (1972) and NASA (1972a, b) before launch and by NASA (1972c, 1972d and 1973) after the mission. Wolfe *et al.* (1981) summarize the results at Taurus-Littrow and show the best estimate at the time of the rover routes.

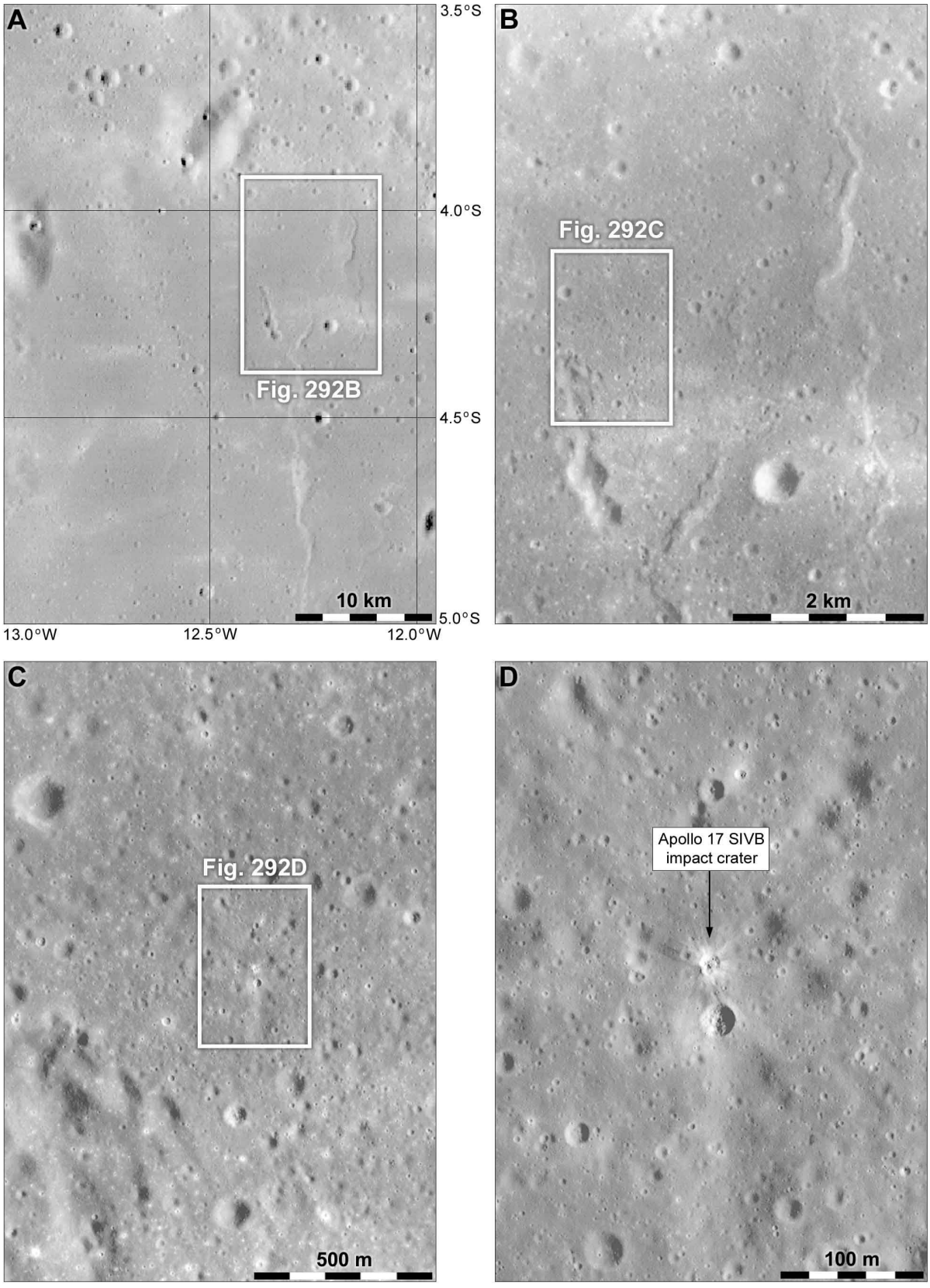


Figure 292: Apollo 17 SIVB impact site.

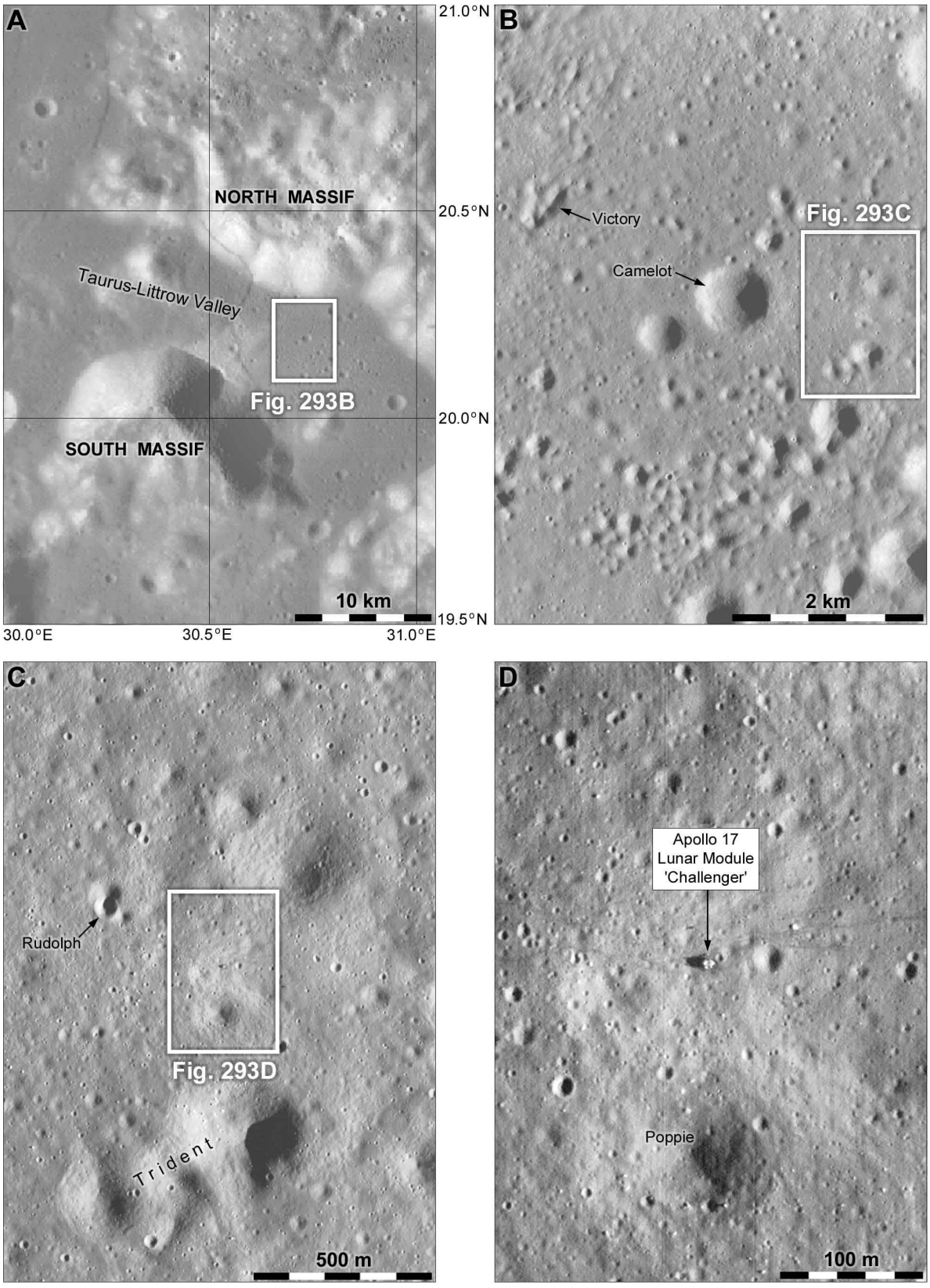


Figure 293. The Apollo 17 landing site. C and D are from LROC NAC image M162107606L.

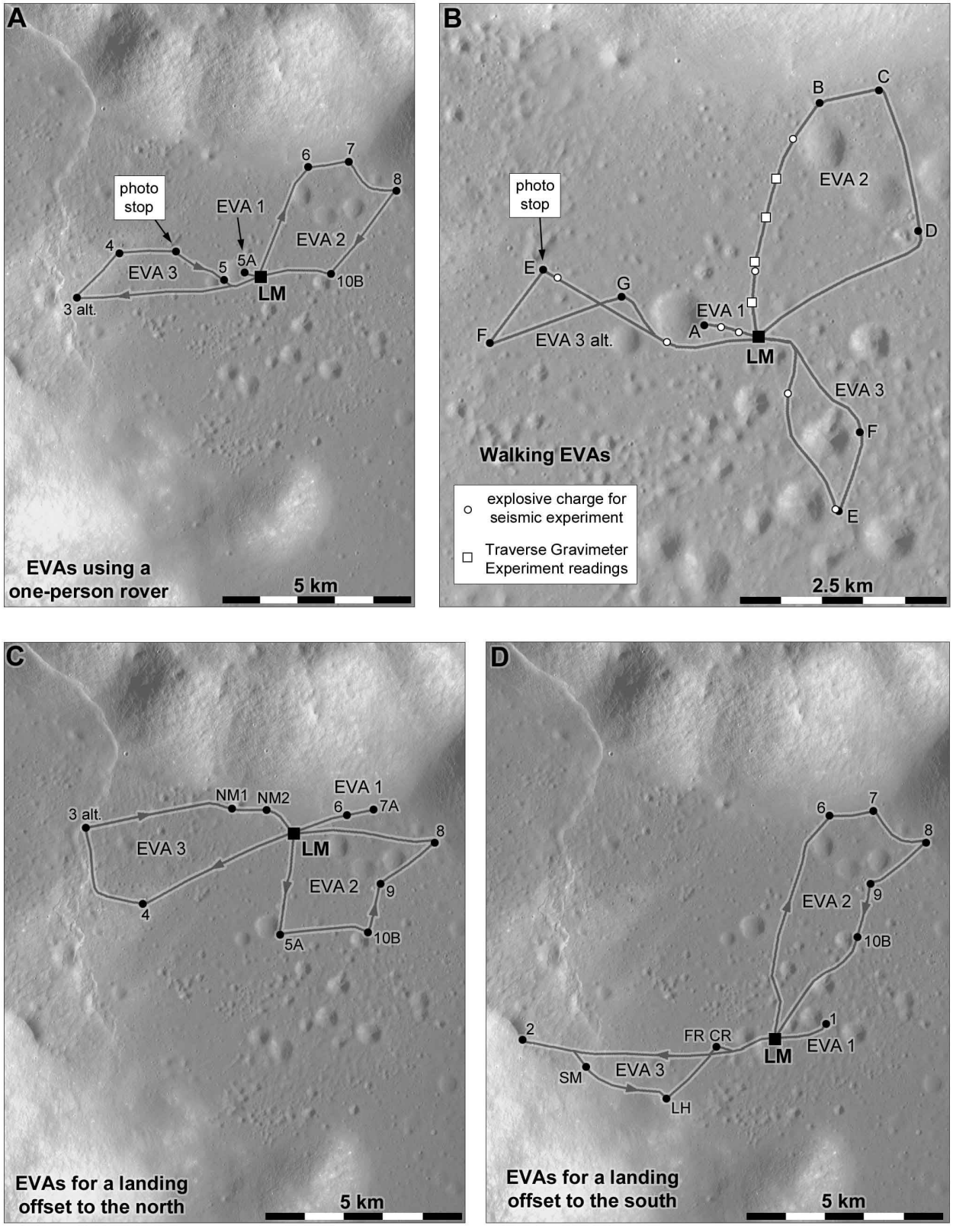


Figure 294. Alternative EVA plans for Apollo 17. NASA graphics used in this figure are as follows: A: NASA-S-72-3207 and 3287-V; B: S-72-3208-V and 3285-V; C: S-72-3206-V; D: S-72-3205-V.

EVA 1 lasted 7.2 hours, and covered a distance of about 3.3 km. Briefly, at the start of EVA 1 the crew erected the flag and prepared the rover. The ALSEP was set up about 200 m west of the LM. This took more time than had been scheduled, so the EVA 1 geology traverse was shortened. The crew drove south about 1.2 km to a point near Steno crater (later renamed Steno-Apollo to avoid a conflict with an existing Steno crater on the Moon). An explosive charge (EP-6) for the Active Seismic Experiment was emplaced, and samples were collected. On the drive back to the LM another charge (EP-7) was set down beside the rover, and Cernan drove a circular loop around it while Schmitt photographed a panorama, all without dismounting. Back near the landing site, the Surface Electrical Properties (SEP) experiment was set up 150 m east of the LM. The rover was driven north-south and east-west to lay out a cross with its tracks, and the SEP cables were laid out along the tracks. A more detailed account follows. Figure 297 shows the planned landing site and EVA 1 route in grey, drawn on an LROC NAC mosaic base. The actual LM location and route are shown in black.

Challenger landed at 19:55 UT on 11 December 1972 and Cernan announced "OK Houston, the Challenger has landed". Ron Evans, orbiting above, was able to follow the landing audio as it happened and congratulated the LM crew as they set about preparing the LM for its stay and for an emergency takeoff if it should be necessary. They landed in their space suits with helmets and gloves, and now they removed the helmets and gloves to make work easier in the LM. A quick look at the surface suggested rover mobility would be good, and they had landed with nearly two minutes worth of fuel left so Schmitt said they should have flown over to look at the scarp. The CapCom (Capsule Communicator) throughout the first EVA was Bob Parker.

They were told they could stay past the first emergency liftoff time as they provided a geological commentary, notably referring to the many boulder tracks visible on North Massif. Cernan used a small telescope to take star sightings to confirm the alignment of the LM attitude sensors. Both astronauts applauded the handling of the LM and the fidelity of their training simulations. Cernan tried to determine their location by looking at nearby craters, thinking he could see Trident and referring to two of its three components as Trident 1 and Trident 2. In fact he was looking at Poppie. The individual components of Trident were not numbered on mission maps and Cernan had to explain to Fullarton in Houston what he meant by Trident 1.

The crew had lunch as they discussed their location and the nearby rocks and craters, notably the very prominent 3 m boulder later named Geophone Rock (Figure 295, 314, 319). Then they talked about the surrounding massifs until they had to be reminded to prepare for the first EVA.

The astronauts prepared for EVA 1 by packing an Equipment Transfer Bag (ETB) with cameras and other items, and by donning and testing the PLSS backpacks. When they had their helmets and gloves on again the cabin could be depressurized, first with a small valve to remove most of the air and then by opening the hatch. As the hatch opened and air streamed out it carried with it any loose items and ice crystals formed as the moist air cooled, and they commented on the flying debris.

Cernan climbed backwards out of the hatch, always a complicated process in the cramped cabin. As he backed out onto the porch he pulled the lanyard to open the MESA, which did not have a TV camera to show his climb down the ladder unlike every other MESA on landed LMs. On Apollo 16 the TV camera was present but not used to save battery power, and on this LM it was not used until placed on the LRV later in EVA 1. Schmitt passed the ETB out to Cernan who lowered it to the surface on a lanyard.

As Cernan reached the footpad and stepped onto the surface he said "I'm on the footpad, and Houston, as I step off at the surface at Taurus-Littrow we'd like to dedicate the first step of Apollo 17 to all those who made it possible." He told Schmitt that they had landed in a very shallow depression and noted the boulder tracks on North Massif and a small crater with a glass-covered floor near the MESA. He thought the Sculptured Hills had the texture of "the wrinkled skin of an old, old, hundred year old man".

As Schmitt emerged feet-first from the hatch Cernan inspected the LM. He was trying to ascertain where he had landed and first thought he was just downrange of Punk. He walked east about 30 m to a small crater he was probably thinking was Punk, and then maybe Poppie (named after his father) but decided it was too small and then walked southwest to the edge of a larger subdued crater which he thought might be Trident but was indeed Poppie. Some of this confusion was caused by the location of the planned landing site (Figure 297), west of Poppie and

north of the western end of Trident. After checking the size of Poppie with Houston he decided that this was the crater he was looking at. He urged Schmitt not to lock the LM hatch, by now an old Apollo joke.

Schmitt's foot slipped on a debris-covered rock beside the footpad as he stepped down, but he was gripping the ladder and did not fall. Schmitt helped Cernan deploy his antenna, which was strapped down during exit from the LM hatch to protect it. Cernan noted 'sparklies' in the soil, crystals or glass shards, and Schmitt observed rocks which appeared vesicular, pocked with bubbles, and slightly pink. Schmitt then put the ETB on the open MESA, adjusted the height of the MESA to make it easier to work on and removed thermal blankets. Meanwhile Cernan inspected the rover, strapped in its folded configuration to the LM on the opposite side of the ladder from the MESA.

Schmitt climbed up the ladder to release the rover, and then both astronauts pulled the cables which lowered the rover and allowed it to unfold and lock its wheels into place. The deployment went smoothly, and when the vehicle was free of the LM the astronauts picked it up and moved it a few metres, setting it facing to the east. They attached fenders and Cernan picked up a piece of glass and put it on the rover floor to bag later. He fell as he tried to pick up a tool they had dropped, already getting his suit very dirty.

When the rover was ready Schmitt returned to the MESA for a camera and Cernan mounted the rover. His visor was dusty and needed to be brushed clean. Schmitt walked to a position NE of the LM and took a panorama while Cernan prepared the rover for its first drive. He drove counterclockwise around the LM, moving slowly east, north and west again and Schmitt photographed his progress. South Massif was in the background and Earth was higher in the sky in the same direction, but Schmitt could not include it in the pictures with Cernan.

Now Cernan decided to take the rover on a short test drive about 100 m to the east and back again, parking north of the LM near the MESA. He had looked around during the drive to help determine their exact location but was still confused about the identities of Poppie and Trident. Schmitt described the rocks and regolith and fell over while trying to pick up a rock, so both astronauts were already very dirty.

Cernan set up the antenna, TV and other gear at the front of the LRV while Schmitt prepared the geology equipment at the rear. As they worked Schmitt saw the scissors they had carried down in the ETB, but which had fallen out by the MESA. The crew had three scissors for cutting open food pouches and other essential tasks, but Evans had mislaid his in the Command Module before the undocking and had been left one of the two remaining scissors, leaving just one for Schmitt and Cernan on the surface. With the usual two on the surface one could be in the cabin at all times, the other outside, but Cernan and Schmitt had to carry them back and forth and losing them would make eating difficult. They picked the scissors up later.

With the high gain antenna deployed and the TV camera mounted on the rover the first TV transmissions began, controlled again by Ed Fendell in Houston. He began a panoramic survey of the site as preparations continued. Schmitt picked up the scissors to keep them safe as Cernan collected the U.S. flag. They would deploy on the Moon the flag which had been hanging on the wall of the Mission Operations Control Room (MOCR) in Houston for all previous landings, and they also carried a new flag which would take its place in Houston after having been to the Moon.

The two astronauts worked together to set the flag up, hammering its staff to fix it solidly in the surface. Schmitt photographed Cernan with the flag and said "Houston, I don't know how many of you are aware of this, but this flag has flown in the MOCR since Apollo 11, and we very proudly deploy it on the Moon to stay for as long as it can in honor of all those people who have worked so hard to put us here and to put every other crew here and to make the country, United States, and mankind, something different than it was". Then Cernan photographed Schmitt with the flag and crouched to be able to fit Earth into some of the pictures he took.

Cernan took the Surface Electrical Properties pallet out of its storage area for deployment later in the EVA. Schmitt deployed a cosmic ray detector on one of the LM leg struts and then opened the storage bay to remove the ALSEP. The Gravimeter had been set up on the LRV and Cernan now took a reading and reported it to Houston. The RTG was set out and fuelled carefully by placing the hot plutonium rod inside its container, but they had trouble removing the rod from its storage cask. Cernan managed to free it and the fuelling was successful. The ALSEP storage bay doors were closed again to prevent overheating of the LM.

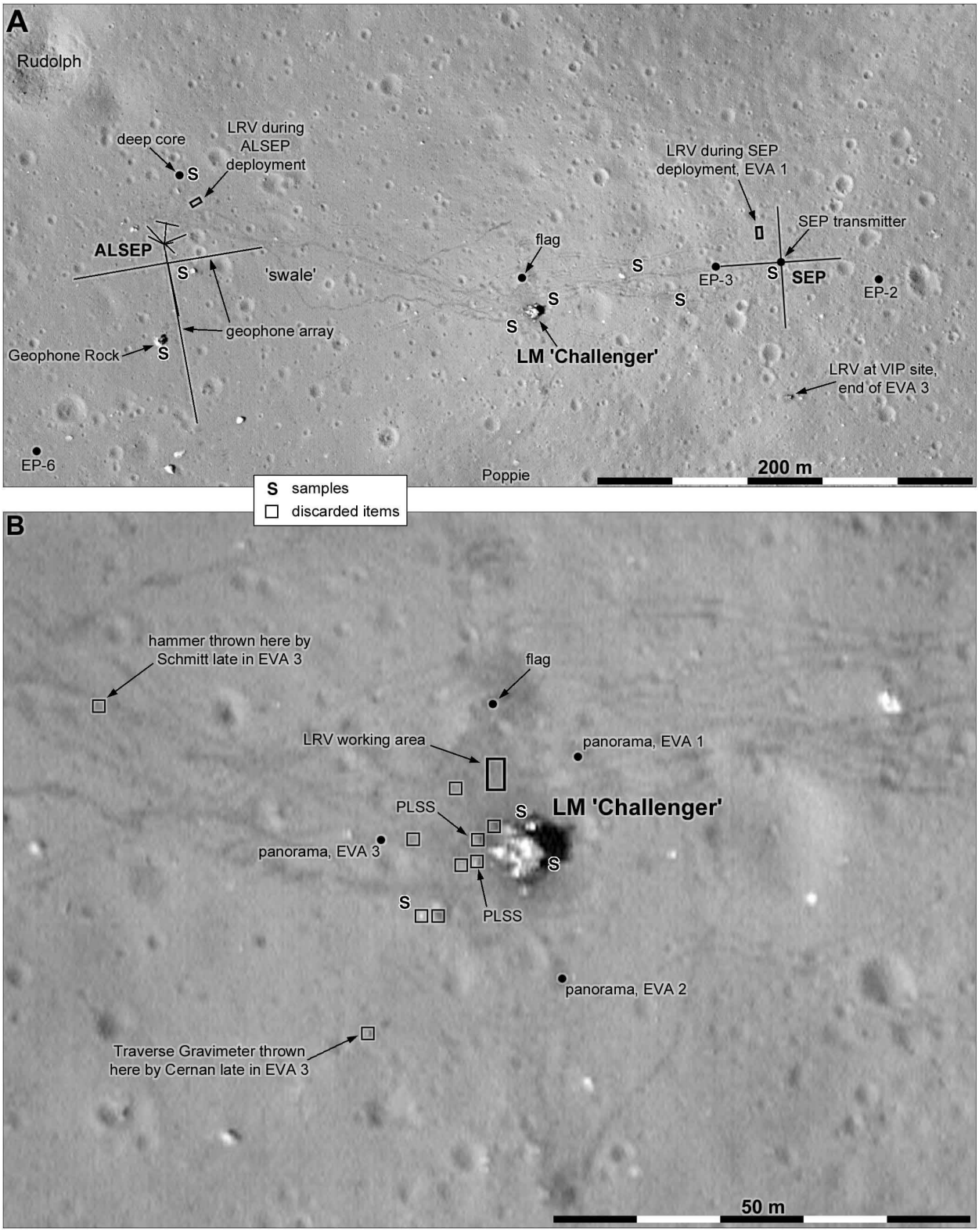


Figure 295. Landing area. A: ALSEP, Lunar Module and SEP areas. B: the vicinity of the Lunar Module.

Schmitt set up the now familiar barbell configuration of the ALSEP and walked clockwise around the LM and out to the west to find a good place to deploy it. As Cernan worked aroud the LRV the hammer in his shin pocket caught on one of the rover's rear fenders and ripped it off, something that had happened on both previous missions with a rover and repeatedly in training. Schmitt paused several times as he carried the heavy ALSEP out about 200 m from the LM, dropping into a broad depression (called 'the swale' after the mission) as he approached a suitable area and then climbing out of it on a more northwesterly course (Figure 298). As he approached the site he would choose for deployment, Cernan was repairing the rover's right rear fender, holding it on it with tape they carried with them for jobs like this.

Cernan drove the repaired LRV out to the ALSEP site and parked about 20 m northeast of the area where the equipment would be laid out, facing east and with the battery covers open to help keep the batteries cool. The ALSEP area was rocky and uneven, causing Cernan to say he was glad he had not landed here. Schmitt had already connected the RTG to the Central Station (CS) but they were running about 20 minutes behind schedule. The rover TV camera started operating, beginning with a panoramic view of the ALSEP area. Schmitt turned the CS on its side to connect the LEAM and Heat Flow cables to it, and as he worked he dropped packing materials and other discarded items in a pile to keep the site tidy. Cernan was asked to dust off the battery covers but they were clean.

Cernan returned to the ALSEP and carried the Heat Flow experiment 10 m north to deploy it. Schmitt removed the Long Period Surface Gravimeter from the ALSEP package but nearly snagged the LEAM cable with his foot. He carried the Gravimeter out to the west, set it up, pulled off its cover and threw it aside. CapCom reported that Ron Evans, in the Command Module, thought he had seen the LM as he flew overhead, correctly noting that it was on the north side of Poppie. Schmitt finished deploying the Gravimeter and its sunshade. This instrument was intended to detect gravitational waves, predicted by General Relativity, but it failed to uncage properly and was not sensitive enough. Later it was used as a seismometer (Kawamura *et al*., 2008), extending the Apollo seismic network.

Schmitt adjusted the position of the RTG and then moved on to the geophone module, removing it from the ALSEP pallet and accidentally removing the dust cover before taking it south of the CS for deployment (Figure 314). Cernan read out a Traverse Gravimeter reading and Schmitt set out orange geophone locator flags in a cross shape about the geophone module to help lay out the geophones as desired. Then he returned to the CS to retrieve the Lunar Mass Spectrometer and try to level the CS as Cernan prepared to drill the Heat Flow holes. The hole was drilled with three stems (tubes), adding the next tube as the earlier tube was most of the way in. The drill itself had to be removed after each stem was in using a wrench. The CS was eventually levelled (important for aiming its antenna) and then Schmitt secured thermal curtains around three sides of it. Cernan almost fell as he discarded some packaging material, and then used a rammer to push the Heat Flow probe and cable down the tube.

The second Heat Flow hole was drilled next, and Schmitt turned on the power to the CS to see if the antenna was oriented well enough for successful communication. Then he deployed the Lunar Ejecta and Meteorite experiment, setting it out far enough from large rocks that they would not interfere with the detection of low angle ejecta. He took to jumping over the ALSEP cables to avoid catching them on his boot. Next he deployed the antenna which transmitter detonation signals to the explosive packages he would set out around the landing site. As Schmitt returned to the rover he nearly stepped on the first Heat Flow hole and had to jump to avoid it. Cernan placed the probe and cable in the second hole as Schmitt set out the geophones and commented on the size of Geophone Rock, nearly 3 m tall.

Cernan now prepared to drill the deep core and chose a place behind a rock relative to the RTG. A neutron flux probe would be placed in the hole after coring and it benefitted from being shielded from RTG neutrons by the rock. He noted that several small craters here had glass on their bottoms. The multi-section drill core tube was difficult to work with but was completed successfully. Meanwhile Schmitt finished laying out the geophones, documented them with photographs and then brought his geologist's eyes to Geophone Rock. Next he documented the ALSEP site with a panorama and other pictures. The full ALSEP documentation would be time-consuming so Houston suggested using two full panoramas in place of documentation of each instrument. As he took the first panorama Cernan placed a plug in the core tube to hold the contents firmly. Then he collected a treadle-operated jack from the rover which would extract the core from the ground.

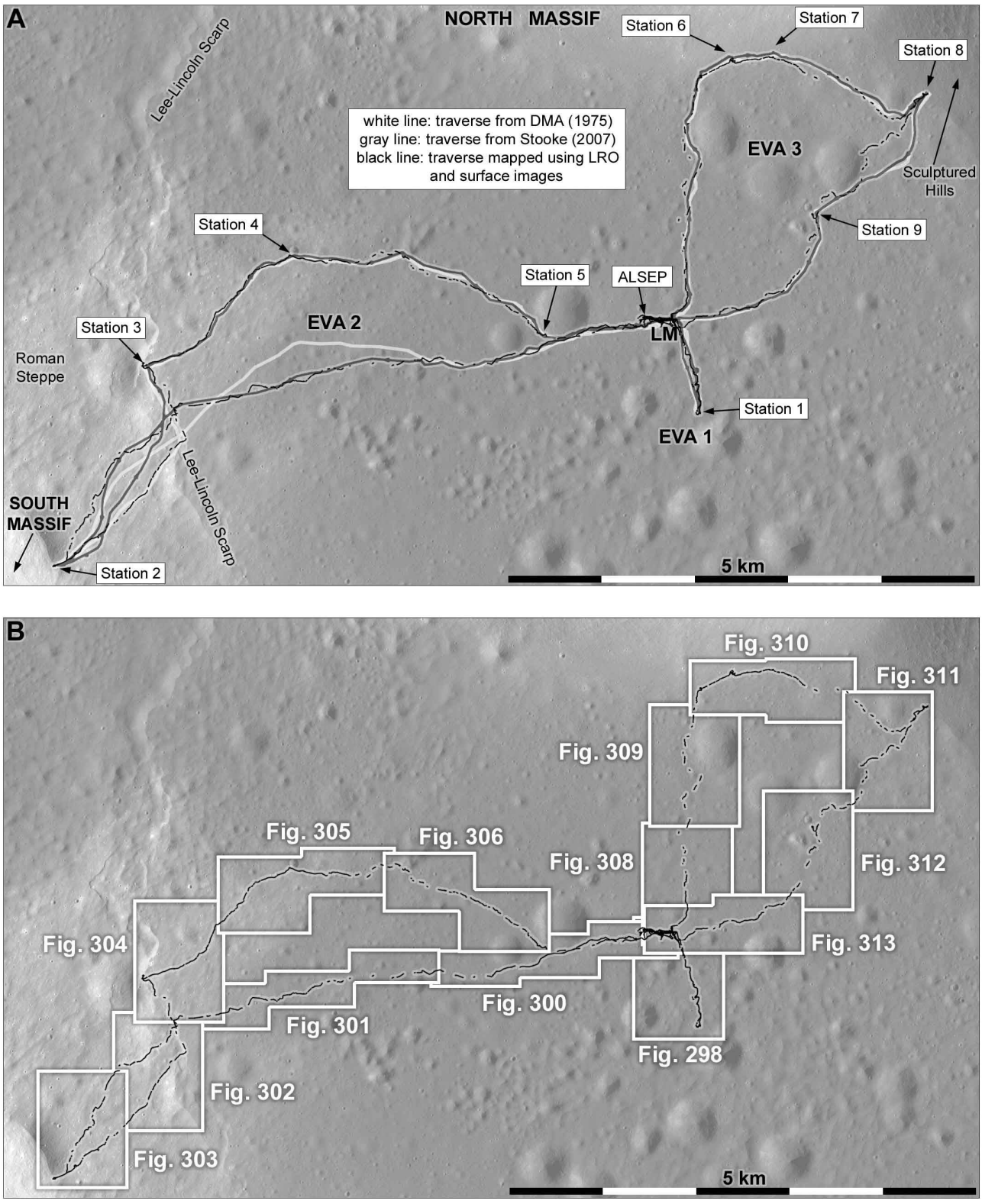


Figure 296. Taurus-Littrow Valley. A: the Apollo 17 traverses as mapped at different times. B: index to the following EVA maps.

While Cernan struggled to extract the core tube with the jack, Schmitt took a second panorama of the ALSEP. He ran out of film and had to change to a new magazine to complete the panorama. Ron Evans was making another pass over the landing site but could not see the LM at the time. Schmitt now joined Cernan to help with the very difficult job of extracting the core. At one point he fell over and Cernan had to help him up again. At last the core started to move more easily and Cernan completed the extraction while Schmitt pressed a button on the CS to enable operation of the seismic experiment (LSPE). Cernan capped the bit end of the core, and with that the ALSEP deployment was essentially complete and a few minutes could be devoted to sampling. Schmitt collected a sample from Geophone Rock and another vesicular rock and Cernan emplaced the neutron probe in the core hole. Schmitt's next sample was from the fillet of regolith around the base of a rock, and he took another near the core site. The EVA up to this point had taken about 40 minutes longer than expected so the science team in the Backroom was now planning to drop Station 1 on the EVA, adjacent to Emory crater, in favour of Station 2 at Steno (Figure 297). Another reason for the change was that Cernan's struggle with the core had used up more oxygen than expected.

Cernan was now at the rover breaking the long core into sections and capping each exposed end. He read out a gravimeter reading, but had forgotten to reset the instrument so he was just repeating the previous reading. Both astronauts now prepared for their geology traverse, gathering sample bags and tools. Cernan retrieved a tool from the Heat Flow Experiment and Schmitt set of walking back to the LM, carrying the core tube sections. As he crossed the 'swale' between the LM and the ALSEP he began singing "I was strolling on the Moon one day...". Cernan joined him to add "in the merry, merry month of...". Cernan added "May" as Schmitt sang "December", misquoting the vaudeville song 'The Fountain in the Park" written by Ed Haley in about 1880.

When Schmitt reached the LM he placed the core tubes on a pair of leg struts, stumbled over a nearby rock, and then picked up the Surface Electrical Properties (SEP) transmitter. He carried it out east of the LM to the area where it would be set up after the geology traverse. Cernan closed the battery covers on the rover, climbed aboard it, bemoaning the fact that he kicked up dust with every move, and initialized the rover navigation system. Schmitt noticed the Station 6 boulders on the lower flank of North Massif and wondered if they would be able to reach them. He was regretting losing Station 1 on the current traverse. He reached the SEP area and found a broad area free of obstacles where they could lay out the experiment.

Cernan now started the drive out to the SEP area, complaining about how difficult it was to drive into the Sun. He parked briefly near the LM to read out a position on the rover navigation system to fix the ALSEP location, then resumed the drive to the SEP area. Schmitt was conveying geological observations to Houston. At the SEP location Cernan read out the rover coordinates again to provide a fix to it, and re-initialized the system for the main traverse. Schmitt climbed aboard (his first time on the rover) and carried one of the explosive charges for the seismic experiment (referred to as 'bombs') in his hands. The original plan had been to carry the charge at this stage because it would be deployed off the side of the rover without dismounting when they passed Steno on the way to Emory. That was no longer necessary but the instructions were still on the cuff checklist and Schmitt followed them, so he could not refer to the maps conveniently and did not take many images along the traverse to help fix the rover path. As a result, the outbound drive of EVA 1 was poorly defined in Stooke (2020, 2022) but additional segments of the route have been mapped in Figure 298 using extreme contrast enhancement of LRO NAC images..

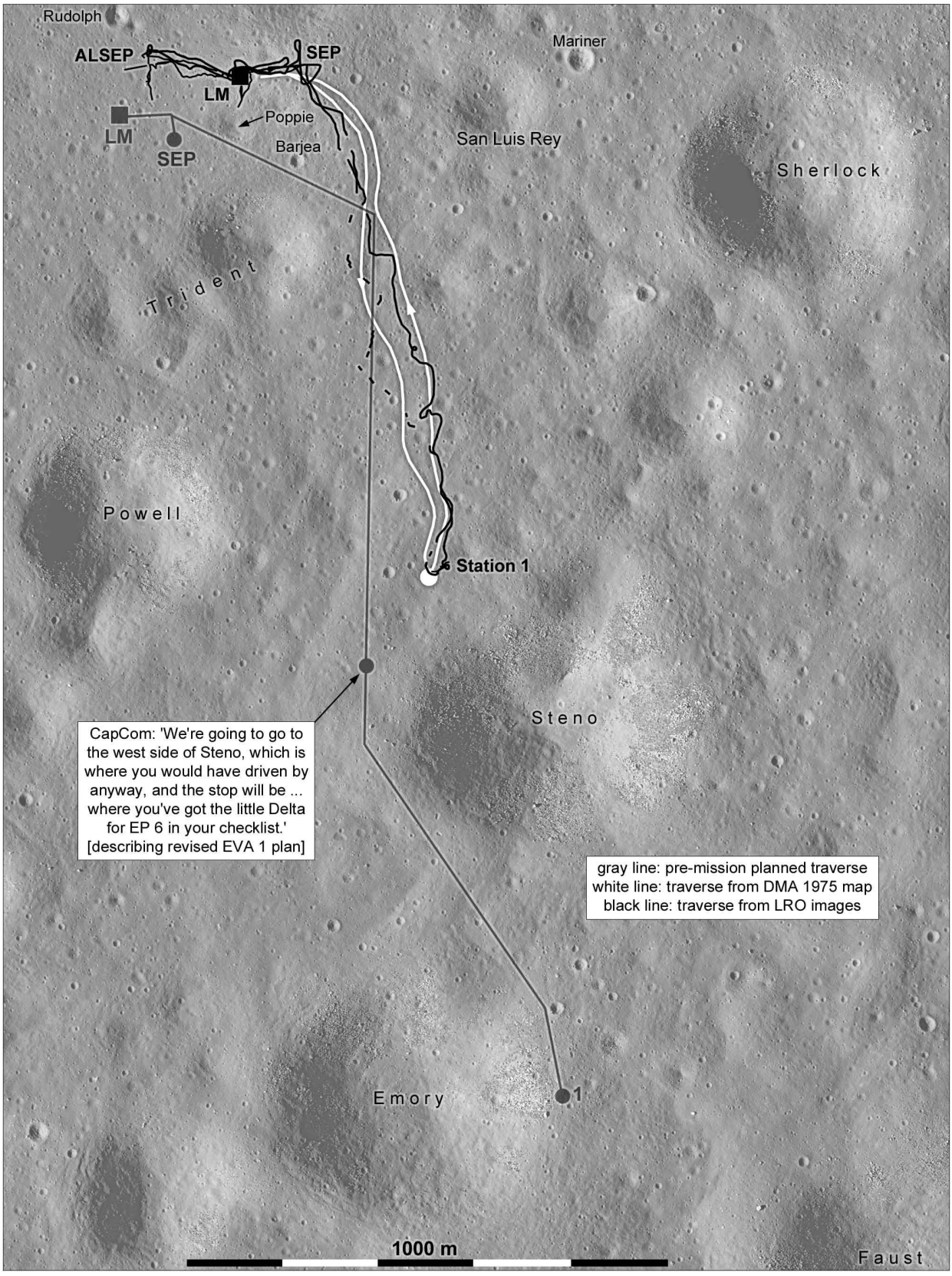


Figure 297. Apollo 17 EVA 1. Comparison of planned EVA, post-mission map and actual EVA.

As they set out for Steno the intention was to stop on its western side where a mark on their traverse map showed the intended location of EP 6 (Explosive Package 6) (Figure 263a). Cernan planned to skirt the Trident crater trio and turn south but they were still not certain where they had landed, causing some confusion among various craters as they drove past. Cernan had seen Poppie near the landing site but had thought it was part of Trident and was surprised now to find what was unambiguously Trident. The lack of visibility when driving towards the Sun made matters worse. Schmitt took a few images here and Cernan added a few more, which help with the reconstruction of the rover path. Houston tried to help but they were still not certain where they were and they decided to stop near a group of rocks and leave the job of fixing the location until later.

This was Station 1, near a 20 m crater (Figure 298) about 250 m from the intended location west of Steno and about 150 m north of Steno's rim. Cernan parked and read out coordinates and Schmitt deployed the charge as soon as he got off the rover. He had tired of holding it and had placed it between his feet during the drive. He pulled pins to activate it, and the charge would be set off later by commands from the LSPE antenna. Schmitt began by sampling a vesicular boulder and Cernan initiated the gravimeter for another reading before joining Schmitt to help with the sampling. He hammered the vesicular boulder and Schmitt collected one loosened fragment. Cernan, standing in a small crater, picked up another fragment and then climbed out. His hands were still tired from the drilling but he hammered the rock again and they described the fragment which included black crystals. Schmitt bagged the sample and placed it in a sample bag hanging on Cernan's PLSS 'backpack', then collected a scoop of regolith from the western, shaded, side of a rock. There was still interest in collecting samples from shaded areas, as at Apollo 16's Shadow Rock, but analysis revealed no obvious difference between them and other regolith samples at these low latitude sites. The first shaded sample was from close to the surface, then a second was from about 6 cm deep. Cernan observed how far away the LM appeared from here, about 1200 m away.

After photographing the sample site Cernan moved on to another rock and Schmitt broke pieces off it with his hammer. This rock had a section with larger vesicles and another with very small vesicles. The samples were taken at the boundary between the different textures. Schmitt then collected a rake from the rover and moved northeast of the rover to collect a rake sample. Cernan picked up a rock near the large boulder thay had just sampled and bagged it. Then he took a panorama of the site as Schmitt was raking, noting that there were many enticing targets for the 500 millimeter lens which they would use later. Cernan then helped bag the rake sample, a collection of small rock fragments, and then Schmitt worked on another goal at this site, a roughly 1 kg sample of regolith. Cernan's camera was covered with dust and he instinctively tried to blow the dust off it, hindered by his helmet. A core sample was supposed to be collected here but Houston advised them that there was no time to do so.

Schmitt returned tools to the rover, Cernan read out the gravimeter reading and looked around at the landscape including the Trident craters, still not sure where he had landed on the undulating valley floor. Schmitt took a final panorama southwest of the rover. When he got back onto the river Cernan advised him how to do it without kicking dust over everything: sit down facing away from the rover, then kick and swivel into place. CapCom Parker advised them where the next explosive charge should be deployed, and when Schmitt had secured his seatbelt they set off, with instructions from Houston to take pictures along the drive. These pictures were not very useful in the years just after Apollo because the small foreground features they showed were too small to show up in Apollo panoramic camera images. They were finally used to reconstruct the traverses by Stooke (2020; 2022) using LRO images to provide unambiguous locations for most pictures.

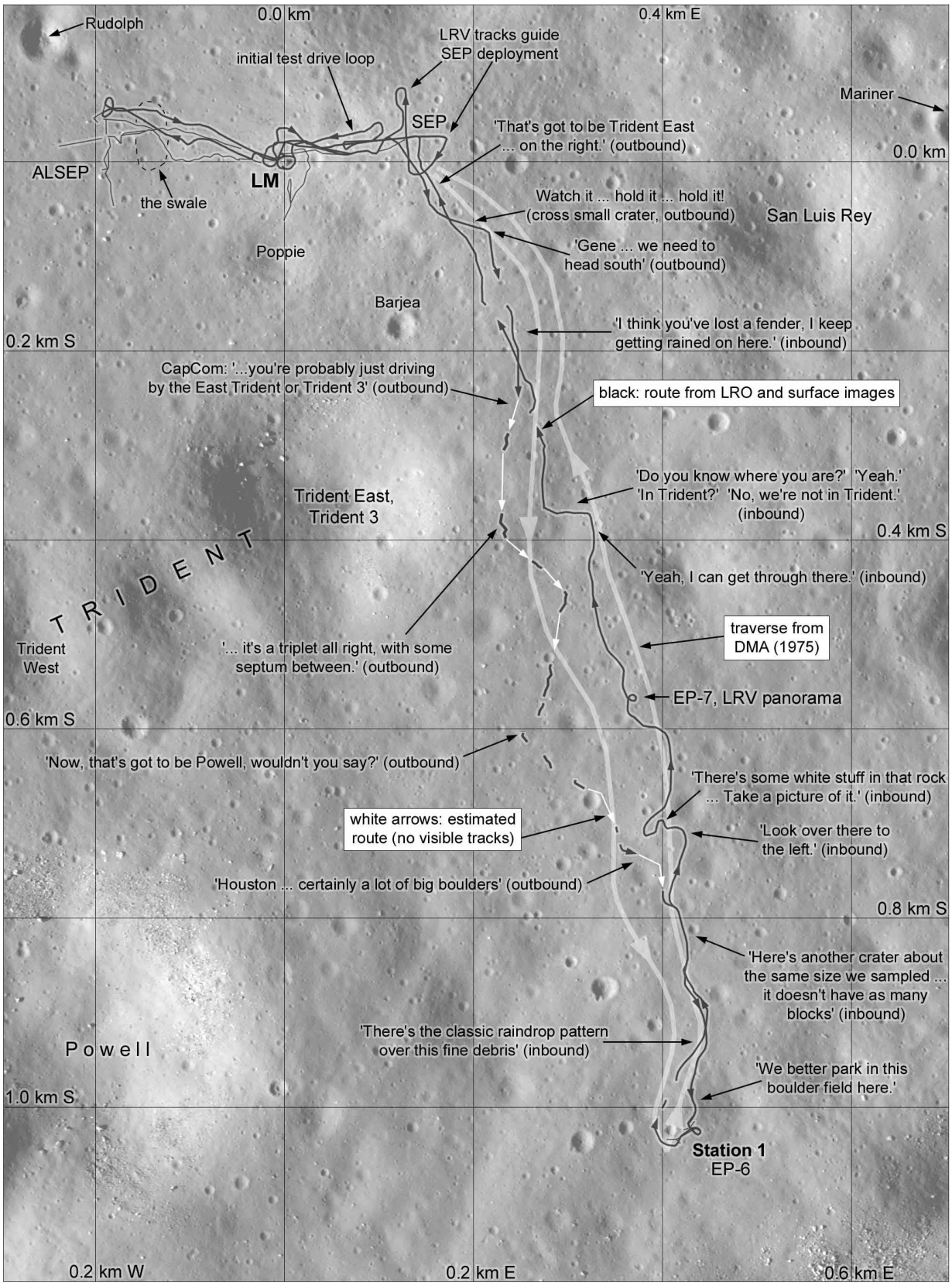


Figure 298. Apollo 17 EVA 1. The outbound route shown here has been updated since Stooke (2020; 2022).

Cernan was watching for landmarks as he drove, noting what he thought were Trident and Sherlock craters. Schmitt made geological observations, commenting on block sizes and a 'raindrop' texture also seen at other sites, caused by a spray of ejecta. He described a crater about the same size as the one they had just sampled but with fewer blocks on its rim, and a small crater with glass on its bottom. Parker requested a range and bearing reading from the navigation system and Cernan called out '341/0.8' (the direction and distance to the LM). Schmitt noted the Station 6 boulder and its downhill track in the distance and after some turning and maneuvering by Cernan he photographed an interesting rock with a white spot made by a small impact but no vesicles. Parker called for another range and bearing (this time 341/0.7) and reminded them to drop the charge at the 0.6 mark. Cernan turned west to allow an image of the white mantle (landslide) area they would visit on EVA 2, then north again and found a place to deploy charge EP-7. Schmitt pulled the pins to enable it, set it down off to the side of the rover, and then took pictures as Cernan drove a clockwise circle around it, taking a rover panorama like those made on Apollo 16 (Figure 318A in Chronicle part 5).

As they drove north again they noted a crater which seemed to contain some exposed bedrock. Passing between two small craters, they drove down into the crater, photographed the rock and read out range and bearing readings. They discussed regolith thrown onto the tops of rocks as they zig-zagged around obstacles, and Schmitt noticed that a wheel was throwing dust up and over him, suggesting the repaired fender had fallen off. They approached the SEP deployment area and Cernan stopped to let Schmitt climb off the rover, noting as he did so the missing fender and dust on the Lunar Communications and Relay Unit (LCRU) which was sensitive to overheating.

Cernan now drove west and turned to face east before initializing the navigation system. He drove about 100 m to the east, turned right and looped around before turning right again to drive roughly northwards over his east-west tracks. This made a cross shape of tracks to serve as a guide for the SEP layout (Figure 298). Schmitt told Houston that they had selected an area with as few craters as possible, south of a large shallow crater and with a very gentle slope towards the LM. Cernan turned south again and parked close to his north-bound tracks. He dusted off parts of the rover to prevent overheating while Schmitt prepared to lay out the SEP cables, which were wound on reels and were proving hard to work with. He was simultaneously talking about geology, speculating that the regolith was mainly pyroclastic material and the rocks around them had been excavated from under the pyroclastics. Cernan completed dusting the rover and took a reel out along the eastern arm of SEP, walking backwards, while Schmitt took his reel out to the west. The transmitter was connected to the cables and was occasionally pulled sideways, causing CapCom Parker some concern as the TV showed it moving. They set the antennae down and Cernan took a picture of Schmitt as they sighted along the lines to be sure they were aligned.

The astronauts reurned to the transmitter and picked up the other two reels. Schmitt walked south and Cernan took his reel north. He noted an interesting brown rock to collect later. They set their antennae down and Cernan took another picture along the line, then straightened the line better. Both men now looked for the brown rock, Cernan picked it up and Schmitt bagged it, but realized it was a piece of foam packing material. Cernan then took a partial panorama including the LM to define the location of the SEP and read out a gravimeter reading. They put some tape on the solar panels of the SEP transmitter to stop them curling. Now Schmitt walked back to the LM and Cernan mounted the rover, commenting that he would have to fix the fender. Schmitt examined a large but mostly buried boulder and collected a football-sized fragment which had broken off it. Cernan parked the rover between the LM and the flag, read out its navigation numbers (helping fix the SEP location) and battery data.

They stowed their samples at the MESA, Schmitt packed the long core sections in a bag and Cernan brushed dust off parts of the rover to keep it cool. Suddenly an object flew past them and they realized a piece of foam packing material from the rover high gain antenna had exploded as the hot Sun heated gas bubbles inside it. Cernan realized the brown object he had collected was also foam, and Schmitt, who had noticed it and thought he was joking, had packed it anyway. Parker told them that John Young had seen the same thing on Apollo 16. Parker now asked for a description of the damage to the fender mount. Cernan finished preparing the rover and Schmitt took a large rock out of the bag it was placed in earlier and put it in a sample box, a tricky job which required Cernan's help. Schmitt took the box and the bag with the core stems up to the LM cabin. Then they dusted each other off as much as possible at the foot of the ladder and stowed their suit antennae. Cernan prepared for a gravimeter reading, then brought a rock box up to the porch outside the cabin and descended again to take the gravimeter reading. He climbed up again and pulled up an equipment bag on a lanyard, then squeezed into the very cramped cabin. They closed the hatch and pressurized the cabin, ending the EVA. It had lasted 7.2 hours.

Both astronauts removed their gloves and suits, noting a distinct gunpowder smell from the lunar dust as previous crews had reported. Bob Parker went off shift and Joe Allen (a future Shuttle astronaut) took over as CapCom. The PLSS units had to be recharged and refilled with water and oxygen, and the suit urine bladders had to be emptied into a sump in the descent stage. Deke Slayton (head of the Astronaut Office, and later an astronaut on the Apollo-Soyuz Test Project in 1975) joined Allen to congratulate the crew. Allen said the ground team were planning a repair to the missing fender. Tape would not hold on the dusty surfaces but the crew had clamps they could use. In Houston a repair was designed and John Young donned a suit and practised it to show it was feasible.

Allen read out some potential lift-off times for use if a quick departure was needed. Schmitt read them back to confirm they were received accurately. Then Parker came back to discuss operations and geology with the crew. He checked that they thought they could drive fast enough for the long traverse in EVA 2, since the EVA 1 drive had been slower than anticipated. Cernan attributed the slow drive to taking time to determine their location and expected no problem in EVA 2. He assured Allen that no material was lost from the long core when it was broken into sections, and that the neutron probe was not directly visible from the RTG which could contaminate the readings. Schmitt told Allen that the local regolith was probably not derived from the local boulders, rather the rocks were excavated from under the dark mantling material.

Cernan said that the tailings around the drill, brought up from below the surface, were the same colour as the surface. Schmitt said there was no obvious layering in the rock outcrops on the massifs, and confirmed that the cosmic ray experiment in the ALSEP and the geophone lines were correctly deployed. There might possibly have been layering in Bear Mountain, but it was hard to distinguish from lighting effects. There was no obvious scar on the massif slope above the landslide. Parker said the science team was calling Station 1 'Station 1A' now (though this was not continued), and its rocks were similar in appearance to Geophone Rock.

The astronauts finished charging the two PLSS units and noted some minor changes for the next EVA. Allen updated them on the orbital operations, which were proceeding as planned for the most part. They were eating during the preceding discussions, and now they began preparing the LM for the sleep period. Schmitt was experiencing an allergic reaction to the lunar dust, the only astronaut to do so during the Apollo landings, but it disappeared after the first night. They set up the suits to dry out during the sleep period and the hammocks were set up. Schmitt and Allen exchanged quotes from Sherlock Holmes stories, and then it was time to sleep after a very hard 20 hour work day.

After the ALSEPs were deployed there were always questions and concerns about them, regarding deployment, activation or the status of equipment. According to Schmit the most critical of these issues concerned the Apollo 17 LSG whose balance beam would not uncage properly, as noted above. This was never resolved so the experiment's main purpose. detecting gravitational waves, was no longer possible. Later it was discovered that there was a mistake in the mass of the beam, and it had not been properly tested for deployment in lunar gravity (Schmitt, 2021).

The Apollo 17 LM 'Challenger' was photographed on the surface from orbit in panoramic camera frame 2309. The bright area around it (Figure 293) was created in part by the descent engine exhaust. This was seen at all Apollo sites. The bright appearance is produced by the removal of very fine darker dust by engine exhaust, or by associated smoothing of the surface. Footprints and rover tracks near the LM look dark in surface images because they disturb the regolith, restoring the darker surface. Tracks elsewhere do not usually appear dark and at the Apollo 17 site they are often invisible.

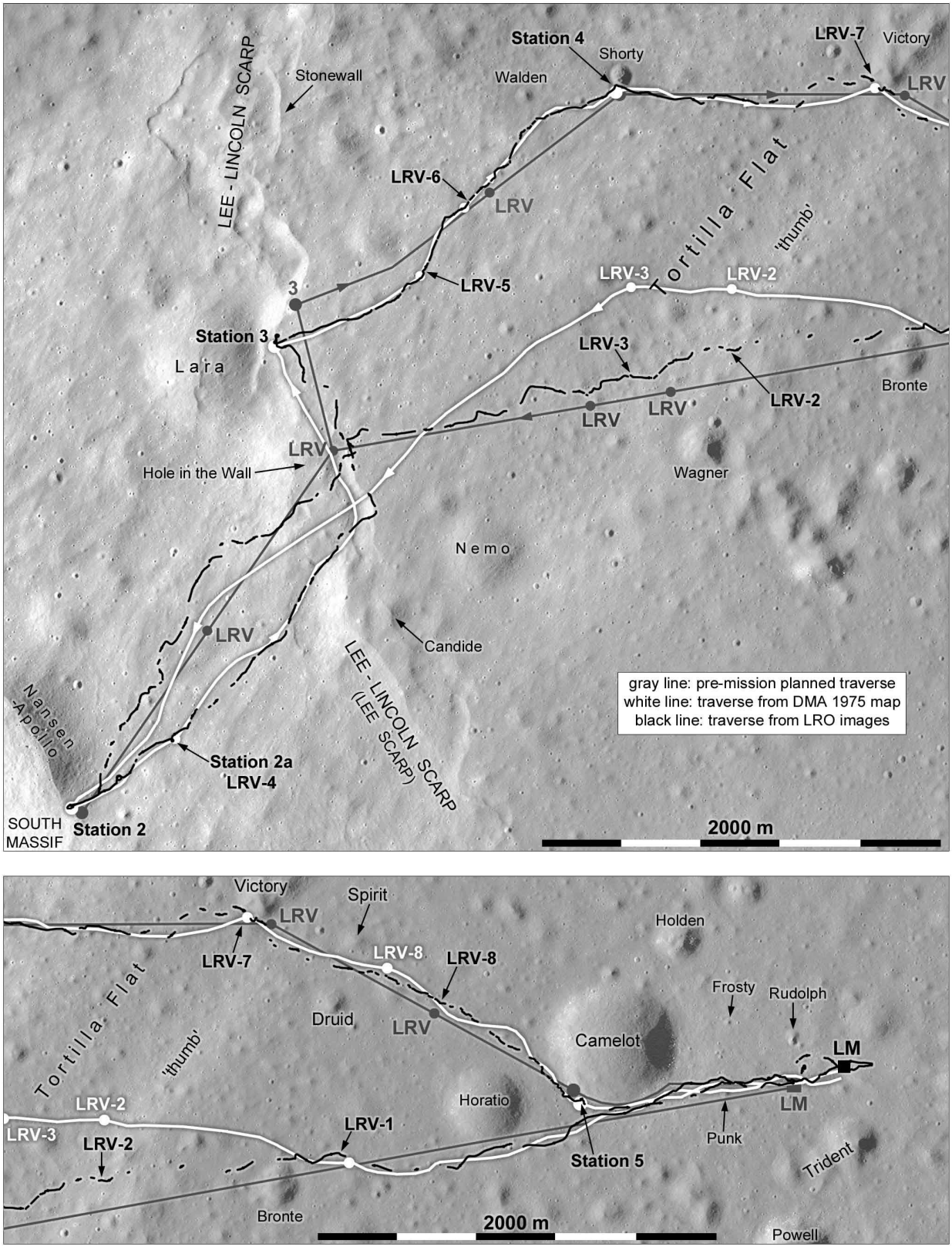


Figure 299. Apollo 17 EVA 2. Overview of the EVA. Figures 300-303 show the outbound journey to Station 2. Figures 304-306 and 300 show the return to the landing site.

In Figure 299 the planned EVA 2 route is shown in grey. The actual route, shown in black, is derived from LRO images and pictures taken from the rover (Stooke 2020; 2022). Some parts of the route are still uncertain. The post-mission map (DMA, 1975) path is shown in white. Figures 300-306 show the new mapping in more detail.

CapCom Gordon Fullerton woke the crew of Challenger with Wagner's Ride of the Valkyries, and they began their basic housekeeping and preparation activities. Fullerton read out a revised list of takeoff times in case an emergency departure was necessary, and Schmitt wrote them down and read them out. Then they had breakfast and John Young came in to explain the rover fender repair he and the ground support team had been working on. This involved taping four sheets of unneeded maps together and using clips to fix this makeshift fender to the rover.

Cernan had been thinking abot the descent and had concluded that they were northwest of Poppie. He asked for a summary of the day's news about Vietnam and the health of former President Truman, sport and weather in Houston. It was cold at home, and he checked by looking up at Earth through the window and commenting on clouds over the eastern States. He said the rotation of Earth over the course of an EVA was very apparent if he looked from time to time. Both astronauts commented on rocks on South Massif and elsewhere. Cernan was looking out at Hole in the Wall, the place where they expected to cross the scarp and head for South Massif. It was almost hidden by a local rise near Camelot. Then they began dressing for the EVA. Bob Parker told the crew that Station 5 at Camelot and Station 10 at Sherlock were more important now because Emory had been omitted. These larger craters would have excavated rocks from under the dark mantling material on the valley floor. He also talked about deploying the explosive charge they had not used at Emory during EVA 3.

John Young now gave Cernan a detailed description of the fender fix and Fullerton checked the PLSS water levels were correct. Cernan constructed the replacement fender out of four map sheets, and then they got into their suits. Schmitt did some LM battery maintenance, balancing power usage. A long series of suit and LM checks and procedures followed. Cernan had been drinking water and commented that the Taurus-Littrow Valley would make a good recreation site if it was flooded, with cabins on the massifs. The helmets went on next, then the gloves. After a suit pressure check, verifying the integrity of the suit, they depressurized the cabin and the EVA officially began.

Cernan opened the hatch and a last gust of escaping air blew some loose material out of the hatch, though not as much dust as they would have liked. Cernan contorted his body to fit his feet through the hatch and eased out, and Schmitt pushed out a jettison bag to be discarded. Cernan attached the equipment transfer bag to the lanyard and it was lowered to the surface, containing the cameras, the replacement fender and other items. When Cernan reached he bottom of the ladder he said "Okay, Houston. On this fine Tuesday evening, as I step out on the plains of Taurus-Littrow, Apollo 17 is ready to go to work." He turned on the traverse gravimeter, last used at the end of EVA 1 and left on the ground in the LM's shadow. Schmitt followed him down the ladder as Cernan activated the rover, and they freed each other's suit antennae from the stowed position. Schmitt pushed the lanyard and commented on it acting as a pendulum, which he had discussed with Parker earlier.

The fender replacement was pulled from the bag and set aside, and film magazines were put under the driver seat for use later in the EVA. An organic contamination witness, a roll of aluminum, was sealed and placed in the rock box as a record of any contamination present before it was filled with samples. Cernan now prepared the gravimeter for a reading, and with difficulty pulled a new battery out of the MESA for use on the rover's communication relay. Schmitt took a colour panorama south of the LM while Cernan put the battery in the rover, and then loaded the rover and prepared for the long EVA 2 drive. When the loading was complete Cernan and Schmitt worked on the fender repair, and afterwards Cernan read out the gravimeter reading and stowed the instrument on the rover for later use. Schmitt was supposed to use the 500 mm lens for close-up photography of the massifs but the task was postponed. He walked out to the SEP site and checked that the solar panels on the SEP transmitter were deployed properly. They had been taped to hold them in place and the tape had survived so far. He turned the transmitter on, took some pictures and collected a small rock.

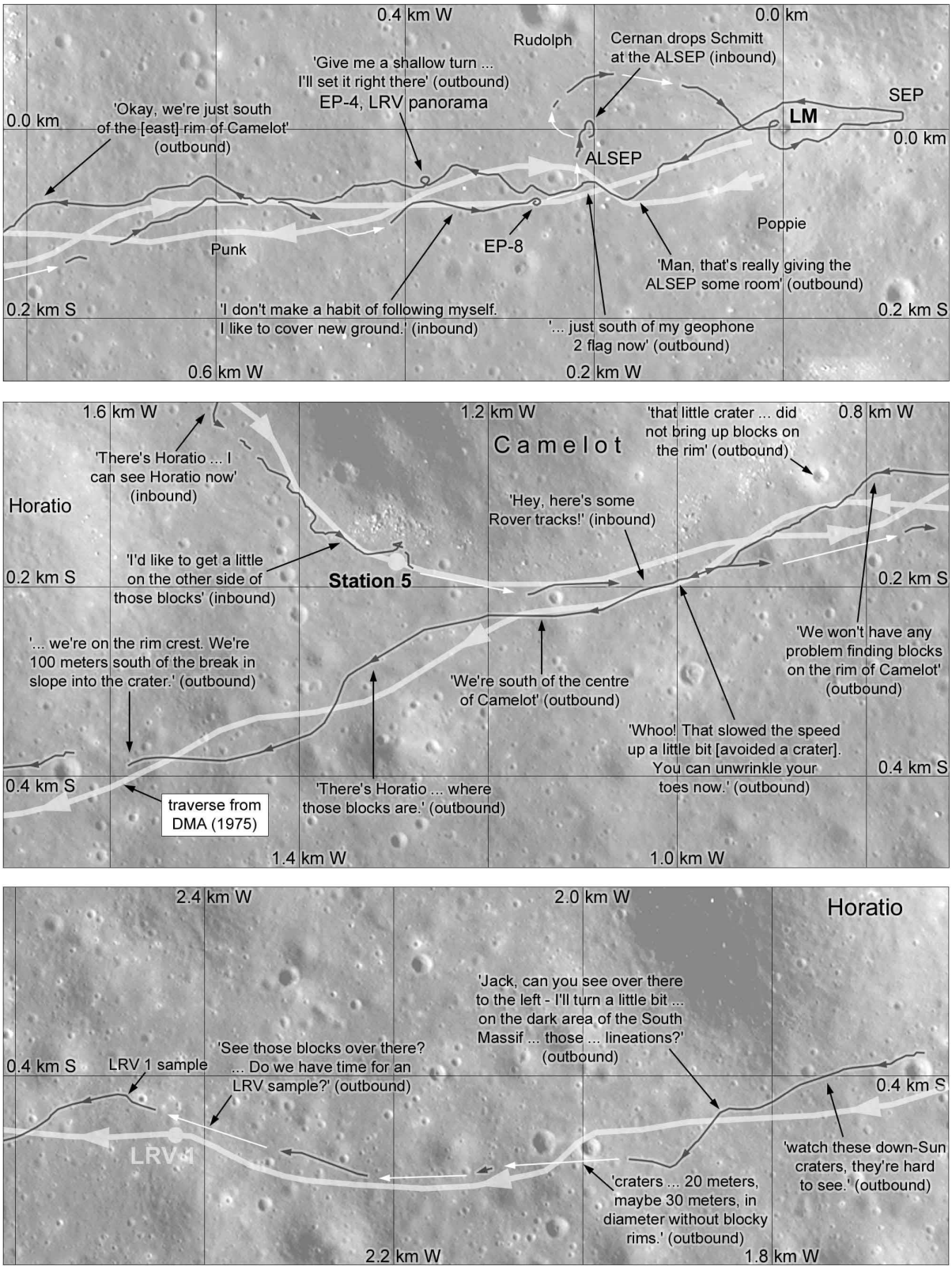


Figure 300. Apollo 17 EVA 2, part 1. This map continues to the west in Figure 301. The top two sections show the return to the LM at the end of the EVA, continuing from Figure 306.

Cernan mounted the rover, read out battery data and set off driving towards the SEP so Schmitt could check the performance of the new fender. It worked as they hoped. Gene approached, avoiding running over the SEP array, and turned to face west. Before leaving, Cernan read out the rover navigation numbers and reinitialized the system. Then they drove back along the west arm of SEP to calibrate its readings, passed north of the LM and turned southwest to bypass the ALSEP (Figure 300). ALSEP was 200 m west of the LM and after another 200 m they were at the location for another explosive charge deployment. Cernan turned to the right, Schmitt dropped off the charge which he had been holding since they left the SEP and pulled the pins to prepare it. He noted that he had lost the head of the tool used to collect samples while on the rover. Cernan drove carefuly around the charge (EP-4) and Schmitt took a partial rover panorama to locate the site. He found the sampler tool head on the floor of the rover and fixed it back on the handle.

Cernan began driving west again and Parker asked the astronauts to look out for rocks on the rim of Camelot, which would be important sampling targets at Station 5. This observation might result in a change in the Station 5 location to be sure rocks were sampled. He asked to be kept informed about any brief stops so Houston could plan the time needed for the return journey, and asked Schmitt to take pictures every 50 to 100 m to minimize film usage. Schmitt made some geological observations, seeing the characteristic raindrop pattern on the surface, noting rocks around some craters and glass-lined pits in the bottoms of bright craters. As they approached Camelot Schmitt asked Cernan to turn towards it while he took pictures. Cernan gave a bearing and range from the navigation system and Schmitt said they would not have any trouble finding rocks to sample. He noted a small crater on Camelot's rim which had not excavated any rocks but saw that the pre-planned Station 5 would have many to choose from.

After Cernan avoided a hazardous crater ("Watch it... You can go around that one") Schmitt described a vesicular boulder and Cernan gave another bearing and range reading south of the centre of Camelot. Then they saw Horatio ahead, and could also see the light mantle (landslide) area, Hole in the Wall and Lara. The surface was less rocky and driving was easier here. As they passed south of the eastern rim of Horatio Cernan gave another navigation reading and wondered if they were near Bronte crater yet. Cernan pointed out oblique linear features on South Massif and turned slightly to let Schmitt see them better. Schmitt described seeing craters without blocky rims and a crater with a large rock on its floor, perhaps a secondary crater. They stopped very briefly so Schmitt could scoop up a sample of ejecta (a breccia fragment) from a 10 to 15 m sharp-rimmed crater and Cernan helped him store it. This was not planned earlier and Parker reminded the crew that the next planned rover sample would be from the 'light mantle', the descriptive name for what appeared to be a large landslide deposit from South Massif. This landslide consisted of a large lobe and a small lobe, and only decades later were they recognized as two separate events, the small lobe ('the thumb') being older.

Moving on again they encountered Bronte, which was more prominent than they expected. Cernan maneuvered around its northern side and followed a narrow 'saddle' between Bronte and a smaller depression on its northern flank. Schmitt noted that there were few blocks here, but many fresher craters with a small central dimple glass in them, and Cernan noted glass in many crater floors. Soon Cernan had to maneuver through complex hummocky terrain, and then they encountered the 'white mantle' (their names for the landslide deposit were not consistent). Schmitt's camera handle now came off, meaning he had to grip the camera to keep it from falling off its mounting bracket on his suit. As they came up to the light mantle Cernan read out navigation numbers and Schmitt noted that craters on the brighter surface had brighter walls, saying they should collect some of that bright material when they stopped for a rover sample. Now they saw a suitable crater and turned slightly to the right to reach it. Schmitt sampled it as Cernan described the area. This was LRV 2 (Figure 301).

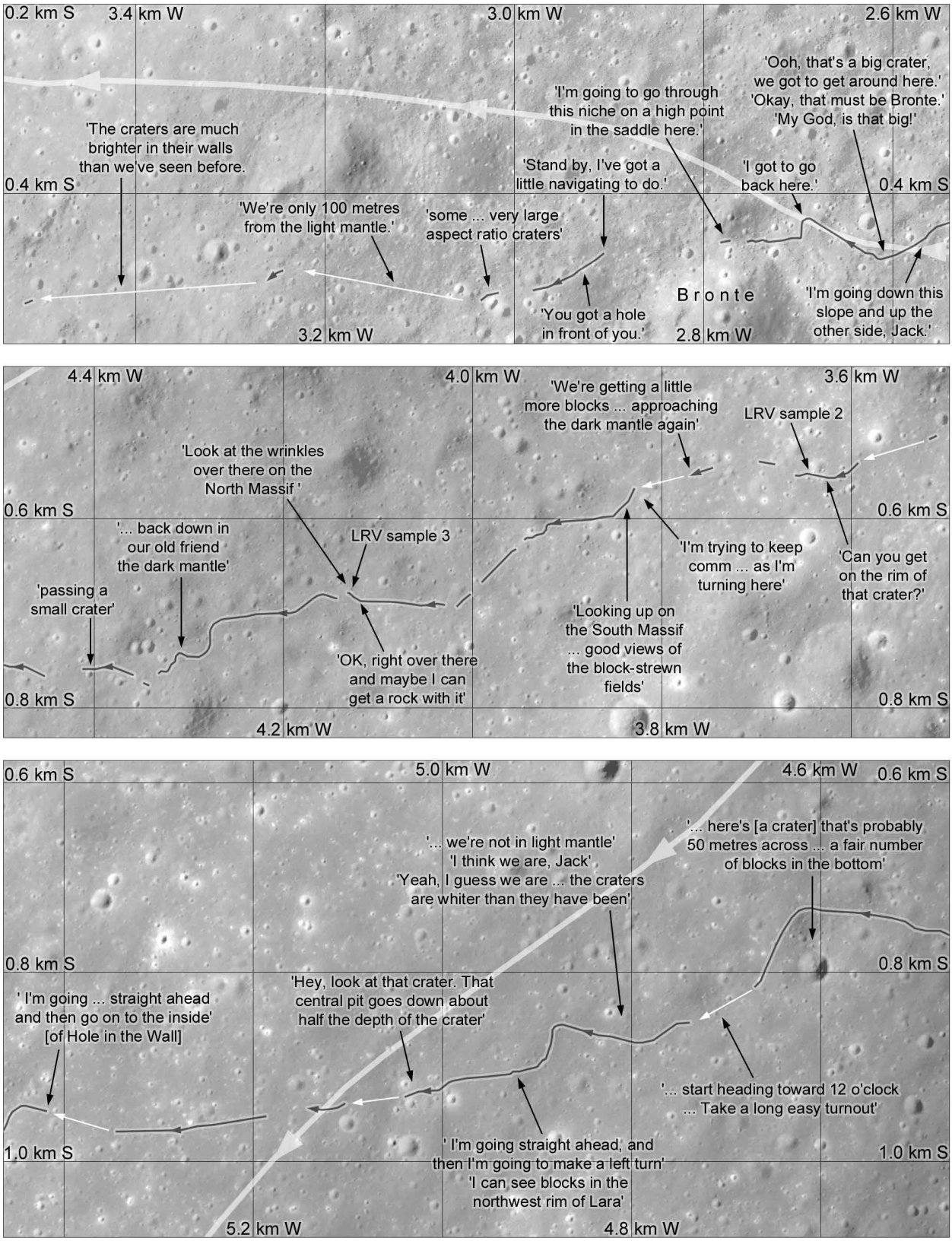


Figure 301. Apollo 17 EVA 2, part 2. This map continues to the west in Figure 302.

They drove on, trying to avoid crater obstacles, and soon approached the dark mantle again. The 'thumb' was only 500 m wide and was separated from the main landslide by a narrow dark surface called Tortilla Flat. Cernan kept Hole in the Wall in view to guide him as he maneuvered through the landscape, and when South Massif was in view Schmitt commented on groups of light tan to white blocks and blue-gray blocks on the slopes. Parker asked for a range and bearing when they reached the dark surface, and another rover sample. Schmitt noted a suitable place and they turned right to reach it. The sample (LRV 3, Figure 301) was a small rock with some regolith. They were now facing northwest, giving a view of the North Massif which Cernan noted had a wrinkled appearance, with the scarp cutting or superimposed on the massif. The nearby crater Hanover was clearly some way up the slope of the massif and would not have been accessible as planners had considered earlier.

They continued moving west-southwest again, describing the small craters. They passed back into the light mantle without noticing a very clear boundary, but saw that small craters were often brighter here than in the darker areas. They saw blocks in the rim of Lara crater on the scarp and noted a small crater near the rover with a prominent central pit. Now Cernan turned left towards Hole in the Wall, where orbital images suggested the scarp could be climbed. Schmitt called out a bearing (081) and a range (5.6 km) to the LM. As they approached Hole in the Wall Cernan noted they would have to bypass a long depression in its entrance and was not sure he could avoid it or drive through it. He decided to turn sharply left and try to mount the Scarp where a gentle slope just south of the entrance might be negotiable. This part of the path was never represented properly on contemporary maps but is made obvious by comparing LRO images with the traverse photography by Schmitt (Figure 302).

Cernan mounted the slope just to the left of a small white crater on the scarp. The rover had no trouble on the slope which Cernan called 'the first tongue of the scarp', and then zig-zagged through the undulating terrain beyond it, heading southwest. The path turned more to the south towards Nansen crater, which had been called Amundsen in earlier planning and later became Nansen-Apollo to differentiate it from another Nansen crater. Schmitt described boulder tracks on South Massif and suggested Cernan head for them, and if they were not apparent at Station 2 they might move the station to the tracks. Cernan drove along a ridge which blocked their direct view of Nansen crater and Station 2, and then down into a broad trough flanking the massif. The trough wall would block their view of the LM from Station 2. More of a concern was that South Massif might block the direct view of Earth, which would mean they would have to move the station.

They approached the massif, passed a 75 m crater with some blocks on its rim, and skirted the rim of Nansen. Cernan drove south and then southwest to the foot of the massif where a scattering of boulders offered sampling opportunities. Only in the last 150 m or so could they see into Nansen and Schmitt noted that the rocks with the best tracks on the massif (allowing a rock to be correlated with an outcrop) were all too far north, well inside Nansen. Cernan drove slowly down the last slope of the rim and chose a Station 2 site near a group of rocks (Figure 303), turning to face northeast before parking. He read out some rover and battery numbers and a bearing and range while Schmitt exulted at the view.

Cernan set up the TV camera as Schmitt worked to tighten his camera handle and then checked the SEP, which was overheating. He turned it off and dusted it to lower its temperature. His sample scoop fell off its handle and he had to reattach it. Cernan joked about changing the oil in the rover as if he was at a gas station back home on Earth, and Schmitt began a geological commentary, noting blocks and the appearance of Nansen. Then they collected several samples from one of the blue-gray rocks, Boulder 1. Parker asked if the local rocks had tracks and Schmitt said no as he and Cernan took flight-line stereo sequences of the rock (several side-by-side stereoscopic views). Schmitt took a sample of the fillet surrounding the rock, on its downhill side and somewhat protected from the solar wind by an overhang. They were interested in the difference between regolith bombarded by solar wind particles and regolith shielded from the solar wind. Not much difference was found. Another sample was taken further from the rock and a third, nearby, was a skim sample containing just the uppermost surface material.

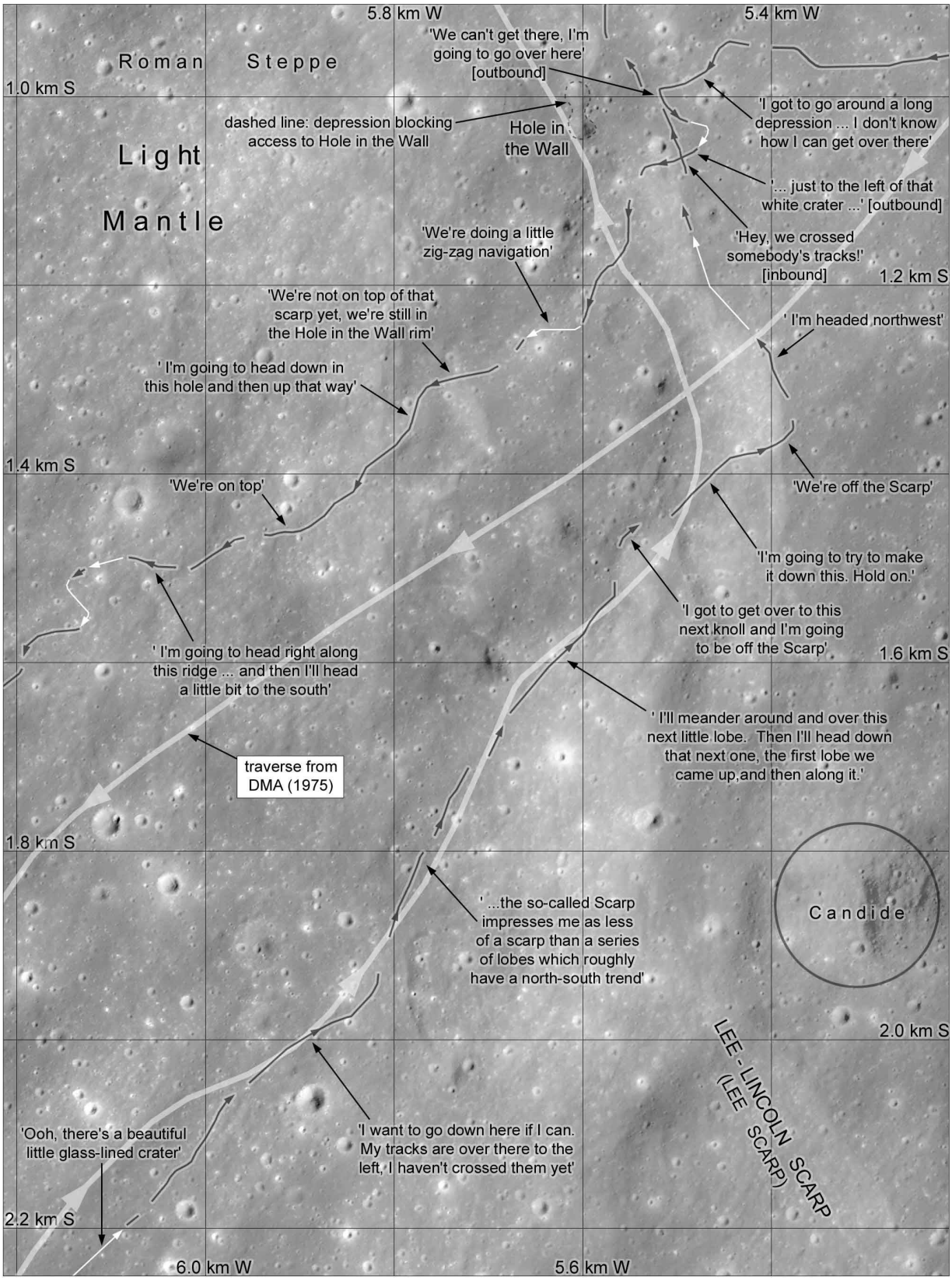


Figure 302. Apollo 17 EVA 2, part 3. This map continues to the south in Figure 303 and to the north in Figure 304.

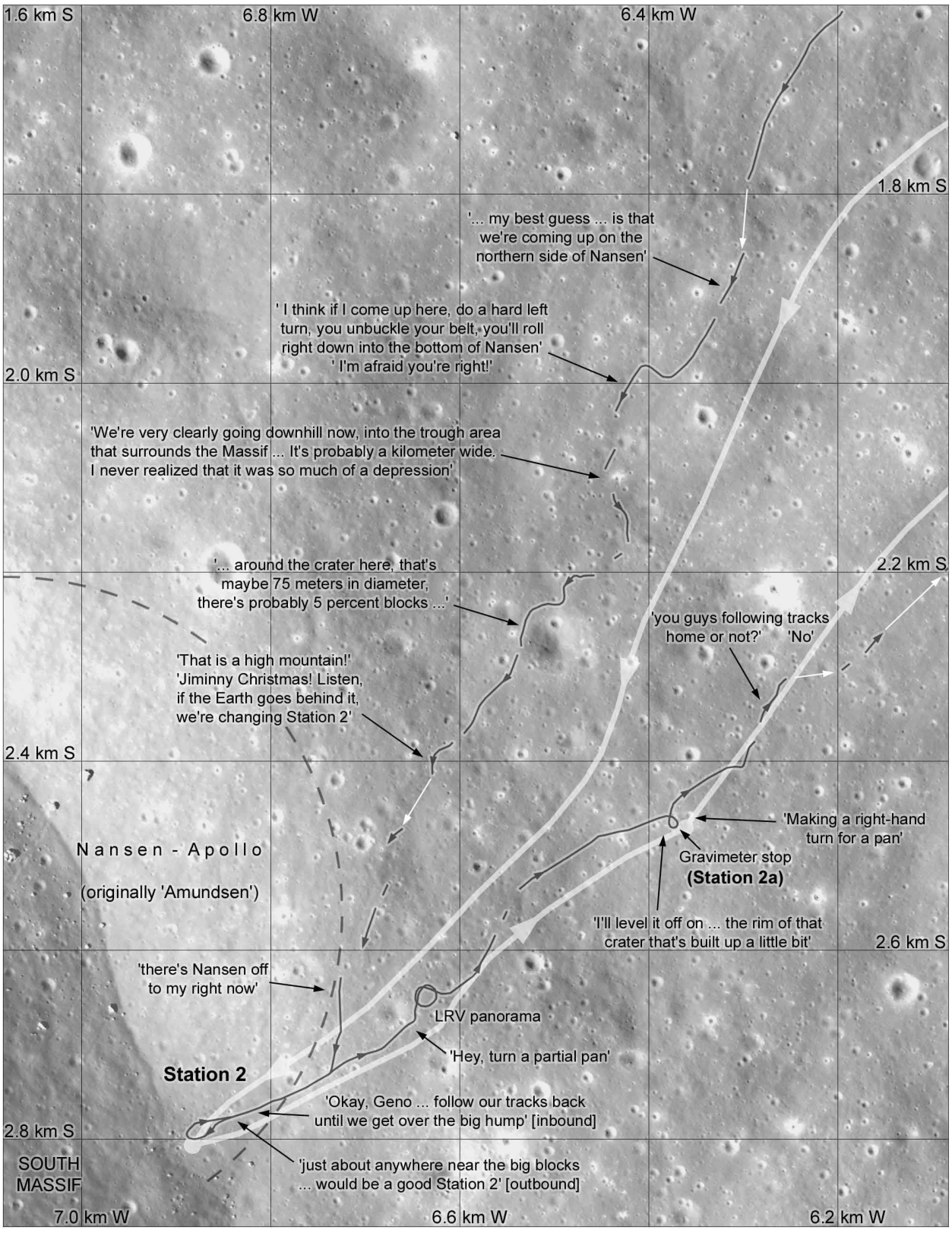


Figure 303. Apollo 17 EVA 2, part 4. Station 2. The route continues in Figure 302.

Cernan now climbed up the slope to Boulder 2. Schmitt called out a gravimeter reading at the rover, and then brought the rake up, noting the surface was softer on the slope. He was irritated by requests from Houston and not convinced the rake was necessary here or that the team on Earth recognized how hard it was to work on this slope. Cernan took a flightline stereo sequence of Boulder 2 and then took a sample from it. The site seemed interesting enough that Parker asked if they wanted to add 10 minutes to their stay and take it from Station 4. Cernan chipped another sample off the rock, and later climbed higher up the slope to take a panorama, standing in a small crater so his feet would be more level. Schmitt collected a rake sample, raking 11 times to gather enough small rock chips to be useful. Then he used the scoop for another regolith sample and Cernan photographed the rake site.

Both men came downhill now and looked at Boulder 3, then sampled it. Schmitt moved to a small rocky crater with a central pit. Cernan pushed a rock with his foot and rolled it a little way down the slope, and Schmitt took a sample of soil under where the rock had been. They returned to the rover and Schmitt took a panorama and then a second rake sample, but it had very few fragments in it. They took another soil sample here, then stowed all their samples on the rover. They had been asked to turn the SEP on before leaving but it was overheating and Parker asked them to leave it off. They finally left the station about 10 minutes late, even with an extra 10 minutes taken from Station 4.

Cernan drove uphill along the rim of Nansen, following his outbound tracks, while Schmitt gave a geological commentary. When Cernan reached the top of the slope he deviated from the outbound tracks to save some time, driving northeast instead of turning north. They were asked to pick up a rover sample as they came down off the highest point of the rim of Nansen. The majestic scenery was too good to miss here so they decided on an unscheduled rover panorama and Cernan drove in a loop as Schmitt took the pictures. They moved a little further and stopped for a gravimeter reading, Cernan trying hard to find a level spot for it. He had to leave one wheel up on a crater rim to level the rover. Both astronauts got off the rover, somewhat reluctantly, but the gravity reading would be compromized by any movement. This spot came to be called Station 2a (Figure 303). Schmitt took the gravity reading and collected a sample from a small crater while Cernan photographed the North and South Massifs with the 500 mm lens.

As Cernan tried to climb back on the rover he slipped and fell, but pulled himself up again. As he did so his boots scuffed the surface, exposing blue-gray clods beneath the surface. After quickly scooping up a sample they started moving and made a quick clockwise loop for a rover panorama. Parker asked if they were following their tracks back and Cernan said they were not. Schmitt noted a small glass-lined pit bottom crater as they passed it. The path took them across the rolling surface above the scarp and Cernan commented that they would have to drive down the face of the scarp rather than out through Hole in the Wall because its mouth was blocked by the depession they noted earlier. Soon they were off the scarp and back on the plains below, turning north-northwest along the foot of the scarp. They passed their outbound tracks and Cernan pointed out the big loop he made to avoid the depression in Hole in the Wall (Figure 302).

Station 3 at Lara crater was visible ahead of them, as was the area where the scarp rose up onto the hills north of the valley near Hanover crater. Cernan read out a range and bearing and Schmitt described another crater with a central pit. He pointed out a rock which might be a good location for Station 3, but Parker mistakenly suggested they needed to move further north. The confusion was soon settled and they turned back to reach the block Schmitt was interested in. Station 3 would be a brief stop because they were running late. Schmitt dismounted and Cernan drove a loop to bring the rover back to the correct position, trying to find a level spot to park.

Schmitt had identified the area he wanted to sample here, a roughly 12 m diameter crater on the rim of Lara, which was a 600 m diameter crater adjacent to the scarp on its upper (western) side and apparently cut by the scarp. Cernan read out the rover data and Parker explained the new plan for this station. Cernan would collect a double core, store it in a vacuum container and take a gravimeter reading while Schmitt did some sampling on his own. Cernan prepared to collect the core near the rover and Schmitt said he had dug a trench in the side of the crater, exposding a 'marbled' light and dark layer under a light-toned surface. He sampled the different materials and then collected some fragments. Cernan was asked to open the SEP blankets and dust them to try to cool the instrument again. Schmitt returned to the rover for more sample bags, then went back to the crater, and Parker told them that Ron Evans had just passed over them.

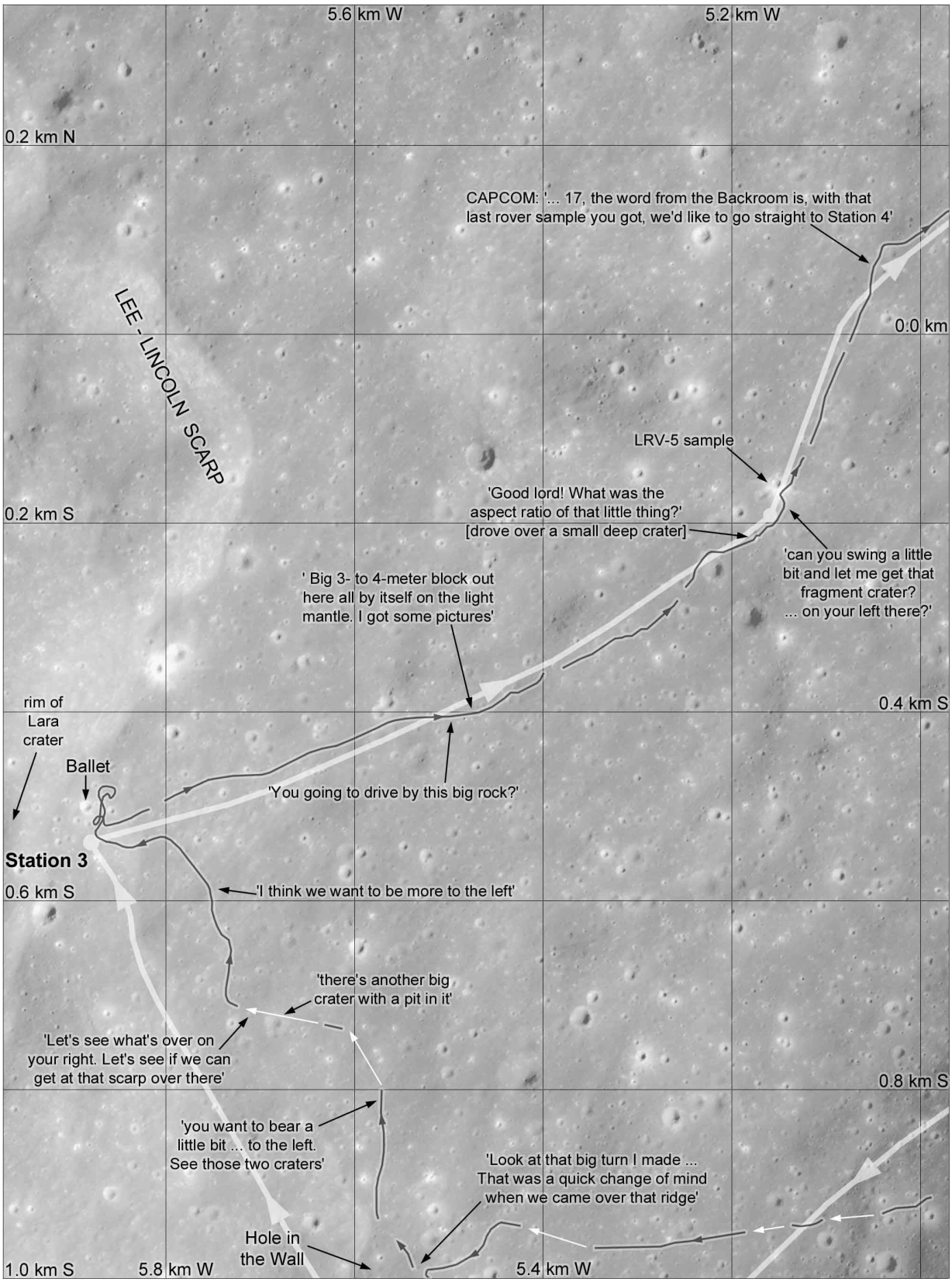


Figure 304. Apollo 17 EVA 2, part 5. This map continues in Figure 305.

Cernan prepared the gravimeter and started hammering a core tube into the ground. When he had driven a double core he stopped and read out the gravimeter readings. Schmitt collected rock fragments and Cernan pulled the core out of the ground. A small amount of material was lost from the cores when they were separated, but soon the lower core was stored in a specialized vacuum container which would not be opened until 2022, when more advanced analytical techniques could be used than were available in the 1970s. This was called ANGSA (Apollo Next Generation Sample Analysis). Cernan stored the upper core as Schmitt struggled with sampling on his own and dropped and retrieved some sample bags, before moving on to take a panorama on the rim of the little crater. His movements during these activities led Parker to joke that 'the switchboard here at MSC has been lit up by calls from the Houston Ballet Foundation requesting your services for next season', and as a result the small anonymous crater Schmitt had sampled came to be known as Ballet after the mission.

Parker continued encouraging the astronauts to leave but other tasks delayed them, including changing film magazines. Cernan took some 500 mm images while Schmitt changed his film, and at last they were ready to move. Cernan drove out over the light mantle area and at one point they passed a large rock which Schmitt captured in several images. Soon after that they saw a 15 m crater with a very blocky rim and drove through its bright ejecta. Schmitt collected a rover sample here (LRV-5, Figure 304). A second rover sample was scheduled in this area but Parker told them to drive on, very concerned about being behind schedule. Cernan and Schmitt had other ideas and stopped very briefly for a sample of light mantle material (LRV-6, Figure 305).

Parker gave them an estimated bearing and range for the stop at Shorty, the dark halo crater on the outer edge of the landslide deposit. Shorty was the feature which had helped locate the landing site because it was thought to be a young pyroclastic deposit around a small vent. Features looking more like small cones or vents had been seen further west in Apollo 15 images (Figure 256A in Chronicle Part 5) but Shorty was the one which was close to the best array of additional targets. As it turned out, it was in fact a typical impact crater which had brought up dark material from under the landslide, and not a sign of young volcanism. It was not the only dark halo (i.e. dark ejecta) crater here, and now the crew saw a dark patch ahead which they thought might be Shorty, but the bearing and range data did not match Parker's figures. It was in fact Walden (Figure 305), They turned more to the east and Schmitt described the hummocky texture he could see on the Sculptured Hills.

Now Shorty became visible across the rolling terrain and a large distinctive boulder on its rim became their Station 4 target. Cernan parked on the rim and commented on the great view into the crater, then read out location and rover data to Parker. Parker then gave them the priorities for this station, samples on the rim and a panorama of the crater. Schmitt described the large boulder, which was crystalline and highly fractured. Cernan dusted the TV camera lens, the battery covers and the SEP. Schmitt was about to start taking a panorama when he noticed orange soil near the boulder in his footprints. He had been fooled, briefly, at Station 3 by orange reflections from Mylar on the rover, and took care to check this was not the case here.

Cernan confirmed it was orange soil (and not Schmitt 'going out of his wits'), Schmitt said he needed to dig a trench and Parker warned them to work fast because time was very limited. Schmitt took the panorama and picked up the scoop he had dropped to dig the trench, and Cernan suggested Ron Evans should operate the lunar sounder (ALSE) over the site. It was supposed to be able to detect any buried water, assuming that rusty iron caused the orange colour, though it would not have resolved Shorty. Evans was told 'While you're doing your pre-sleep checklist, you might be interested that, at Shorty, the surface crew found some very, very orange soil, a great deal of it. Indicates strong oxidation and possibly indicates water and/or volcanics in the area. And they're really...Jack's kind of like a boy at Christmas time. I'll tell you, a little kid at Christmas time on that one.' Later Evans saw other orange patches near Sulpicius Gallus in Mare Serenitatis.

Cernan prepared the gravimeter for a reading as Schmitt dug the trench. Any motion on the rover disturbed the gravimeter reading, so he had to re-set it after a problem with the TV camera: it tilted down and could not be commanded back up from the ground to follow the astronaut activities. Cernan had to tilt it himself and then re-set the gravimeter. The two astronauts sampled patches of the clumpy deposit with different colours, orange and gray. Cernan picked up a piece of black glass and put it in his pocket, then began taking a core sample which Parker had requested. Schmitt helped him cap it, then took a sample off the large heavily fractured boulder. Cernan took a second panorama to give stereoscopic viewing of the crater interior. They returned to the rover, very close to the walk-back limit (the last time they could leave this location and walk to the LM if the rover failed) which Parker was

increasingly concerned about. Cernan read out the gravimeter reading and they climbed onto the rover and prepared to leave.

Cernan made a sharp turn to depart from the crater rim and drove a zigzag path, tacking to avoid driving directly into the Sun direction. Here and elsewhere he was also disturbed by the reflection of the Sun off the shiny LCRU cover. Parker gave them a bearing and range for the expected stop at Victory crater, a V-shaped secondary crater cluster. Schmitt talked through his thoughts about the orange soil, leaning towards a volcanic vent origin, and Parker pointed out that they also had a chance to look at a possible volcanic crater at Station 9 on the next EVA. That possibility had been suggested in pre-mission studies of the site, but Van Serg would prove to be another typical impact crater.

They crossed the outer part of Tortilla Flat, barely noticeable at this distance, and soon approached Victory, noting glass-lined pit craters along the way. Cernan pointed out a square boulder as they approached the rim, then called out a bearing and range. Schmitt indicated a spot where an explosive charge could be put down, large enough that the rover could drive around it for a rover panorama. He pulled pins to activate it and set it down, and then Cernan drove a tight circle around it for the panorama (Figure 306). They took a rover sample here as well (LRV 7), only a couple of meters from the charge. They started to move but Schmitt asked Cernan to turn and pause so he could look at Victory properly, and gave some geological description of it.

As they resumed driving Parker gave them a bearing and range for the location they would use for Station 5. Cernan noted more of the glassy pit craters and Schmitt asked if he had seen any sign of the outer part of the 'thumb' of the landslide. Neither of them had noticed it. They described craters as they passed them, and stopped for a rover sample (LRV-8, Figure 306). Schmitt collected a scoop of regolith and tried to pick up a rock but it was too large. He took a documentation picture and they pressed on, heading for the gap between Horatio and Camelot craters. The original location of Station 5 would have been at the southwestern rim of Camelot but the observations during the outbound drive had suggested a move of about 100 m to the southeast.

The undulating surface made it hard to spot craters until they were close to them, and Horatio's featureless rim was particularly hard to find. Cernan noted that the Apollo 14 astronauts had been standing close to the rim of Cone crater without being able to see it, and now he could understand why. They could see the Sculptured Hills and Wessex Cleft and relayed some observations of its texture and albedo, and more descriptions of the rocks they were passing. Now they saw Camelot and drove close to its rim, and during a turn they finally saw Horatio. Cernan drove past the large block field on Camelot's rim and parked at its eastern end so the rover TV camera would see the sunlit sides of the rocks.

Parker said they were being given a little more time here, 25 minutes, to sample the large rocks and take a rake sample. Parker asked them to open the SEP cover and let it cool, though it was not being used. The overheating was one reason the experiment did not produce a full dataset (Grimm, 2018) and in fact its most useful results were from the first 1.7 km of EVA 2, out to Horatio crater. Cernan put a new film magazine on his camera as Schmitt began examining a rock. He collected sample bags and prepared the gravimeter, then joined Schmitt. Camelot was large enough to excavate blocks from the material underlying the dark valley floor material, so that was the goal of sampling at this station, and they spent most of the time here sampling large blocks.

After working on the rocks Schmitt collected some soil deposited on top of a rock and another fragment broken off the rock. Time was running short so Parker asked them to skip the rake sample and scoop up a bag of regolith. Cernan collected the sample and then took a panorama. As he returned to the rover Schmitt took another panorama. Cernan read out the gravimeter values, they climbed aboard and headed for the LM. Parker advised them where the next explosive charge should be placed, as they approached the ALSEP. He suggested it would be along their outbound tracks but Cernan said he didn't 'make a habit of following myself. I like to cover new ground' though he was only a few tens of meters from the old tracks.

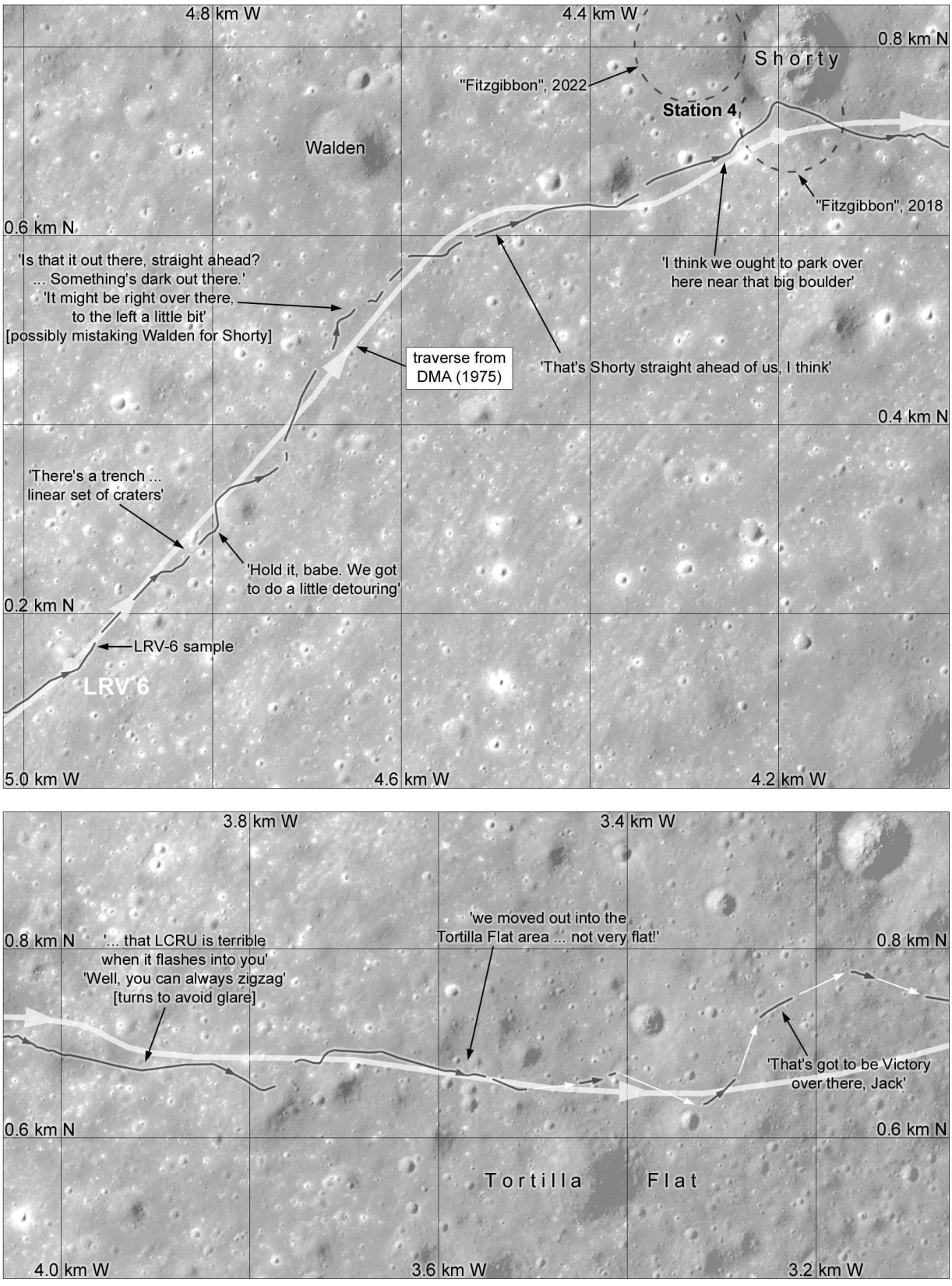


Figure 305. Apollo 17 EVA 2, part 6. This map is continued in Figure 306.

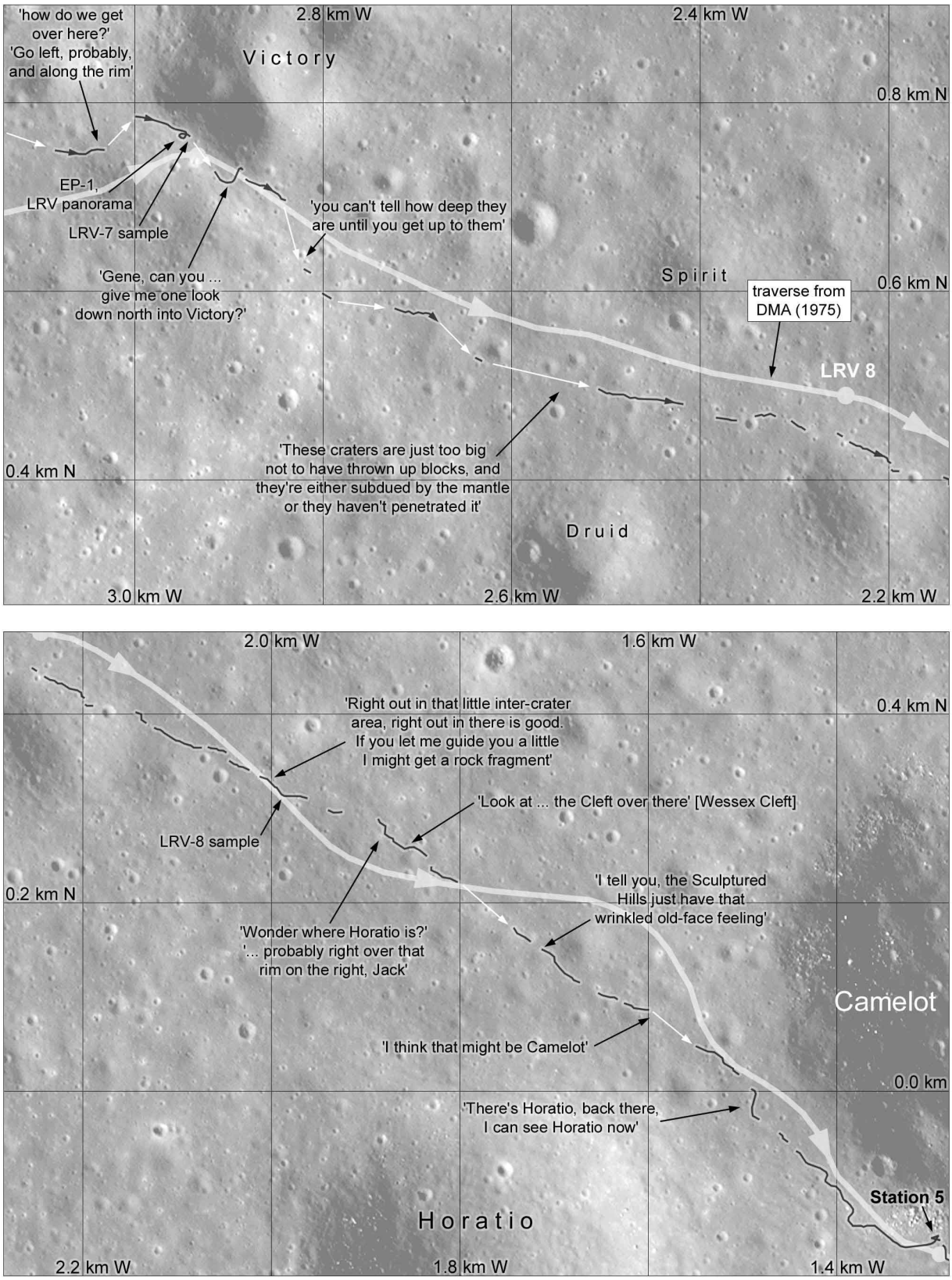


Figure 306. Apollo 17, EVA 2, part 6. This map is continued in Figure 300.

Cernan found a location for the charge and Schmitt prepared it and set it down. Cernan took a picture to locate it as he made a loop around the charge. They moved on and then swung north on the west side of the ALSEP so Schmitt could check the Lunar Surface Gravimeter (LSG). After he dismounted Cernan looped around again and drove north of the ALSEP and back to the LM. The LSG, not the same as the Traverse Gravimeter Experiment on the rover, had to be level and its Principal Investigator, Joe Weber, was concerned that it was not. Schmitt was making sure that it was deployed correctly, and though its bubble level suggested it was right he moved it to test the level. In fact it never operated properly.

Cernan parked the rover near the LM and read out the usual set of numbers. He opened the SEP covers and he and Parker discussed it, trying to find a way to keep it cool. Schmitt walked back from the ALSEP and collected a piece of glass from a small crater. Parker now advised them on the way the scientists wanted samples stored and they worked on stowing everything. Cernan took the gravimeter off the rover and asked Parker to congratulate John Young for the repair to the fender, which had worked perfectly. Cernan took some 500 mm photos of the massifs, then worked on preparing the rover for the rest period, including pointing the camera away from the Sun to minimize heating and dealing with communication issues when the rover LCRU was turned off. He also read out the rover temperature.

The crew now had very dirty suits and wanted to track as little as possible into the cabin. Schmitt dusted Cernan's suit and then Cernan dusted Schmitt's. They stowed their suit antennae and Cernan read out the gravimeter values as Schmitt climbed up into the cabin. Now Cernan mounted the ladder carrying a rock box. Schmitt unloaded a pallet he had brought up, then pushed it through the hatch and Cernan threw it down to the ground. Cernan now pushed the rock box into the cabin and Schmitt stowed it so Cernan could squeeze into the very cramped cabin. They closed the hatch and pressurized the cabin, formally ending the 7.6 hour EVA. They had driven 20.6 km, the record for Apollo.

Both astronauts now went through the complex task of removing helmets and gloves. Parker joked that 'We've got a 9 and 1/2 hour EVA scheduled for you tomorrow. We're planning to spend 2 and 1/2 hours extra over there at Station 4', and then turned CapCom duties over to Joe Allen. They ran air through their suits to help dry them, and began to recharge their PLSS units. Cernan took a small rock out of his suit pocket, one he had picked up at Shorty, saying it should be called Gene's Rock. He read out weights for the sample containers. They removed their suits, putting the leg sections into jettison bags to contain any remaining dust, and then their liquid-cooled garments, and put on longjohns. Allen read out new lift-off times, one for each orbit of the Command Module, in case an emergency departure was necessary.

Allen instructed Cernan on a computer procedure to prevent a clock overflow. He checked the status of Schmitt's helmet visor and wear on the seats of the suits. He asked about the Station 4 boulder, where the science team had heard the word 'spattered'. Schmitt said he had called the rock 'shattered' and said it looked like other rocks they had seen around the valley. They had some food and recharged the PLSS water, and then the oxygen. Allen gave some sport news and advised that the SIM Bay instruments in the Service Module were giving good results including detecting thermal anomalies in Oceanus Procellarum. Urine from the suits was dumped into a tank in the LM. Either now or before EVA 3 the next day, Schmitt took pictures out of the LM window to view the rover and tracks. Allen mentioned cold weather in Houston and said that the ALSEP gravimeter was still not working, and they were trying to solve the problem.

Deke Slayton now came on the radio link to encourage the crew to prepare for the sleep period, as they were putting up their hammocks. They reflected on the tracks being left by feet and wheels here, and when they might be disturbed in future. Finally they prepared for sleep and the long day was over.

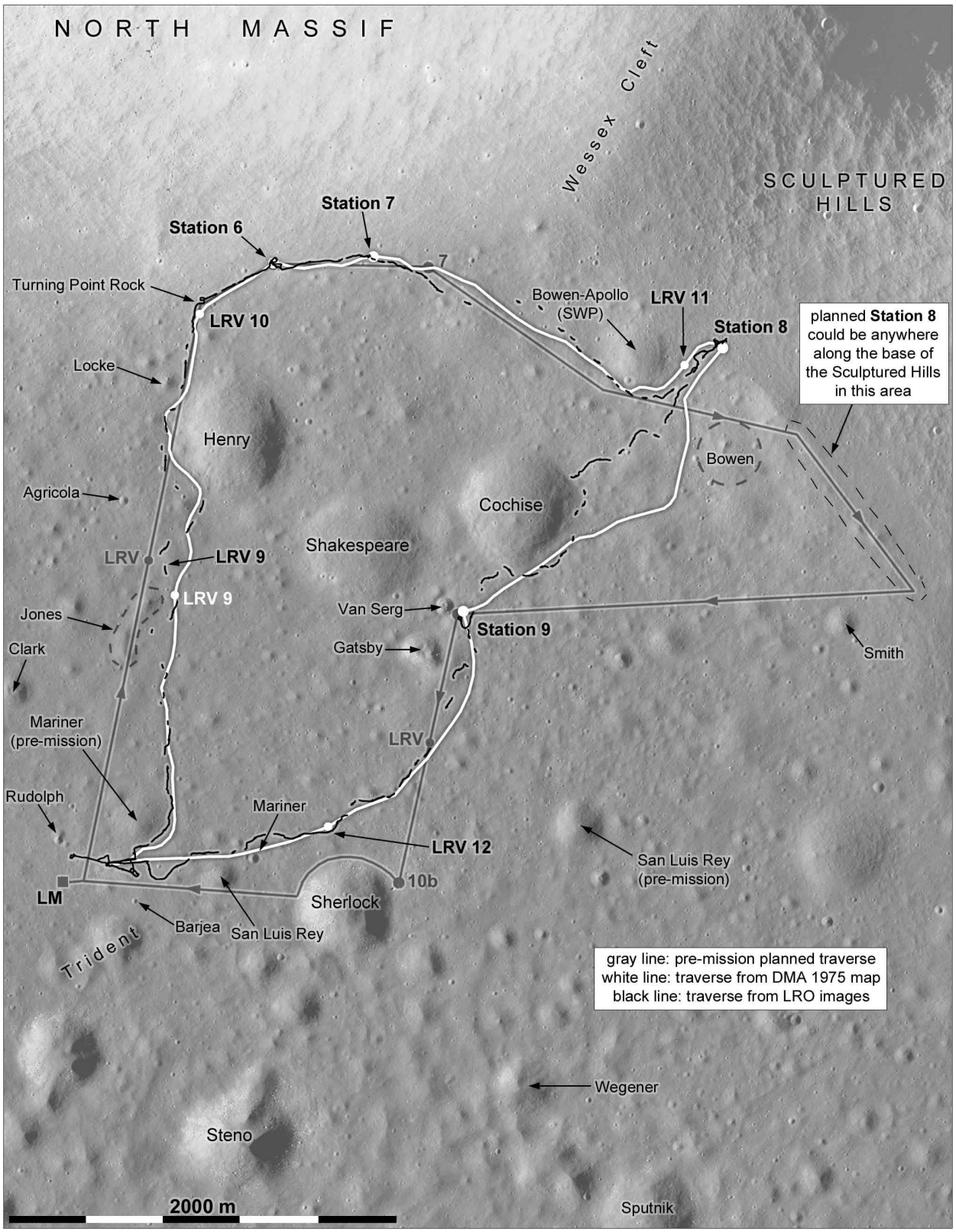


Figure 307. Apollo 17, EVA 3 overview. Figures 308-313 give more details.

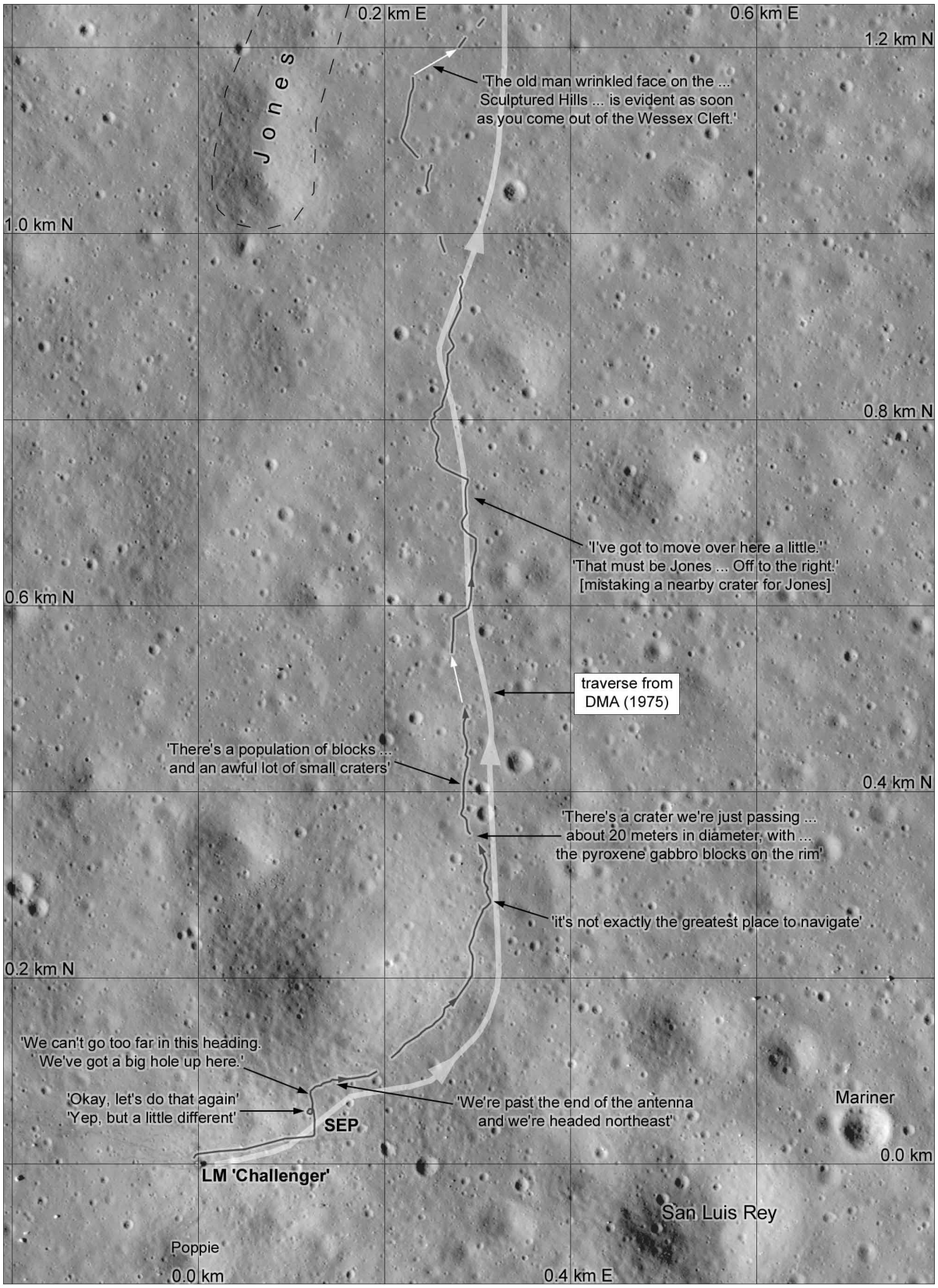


Figure 308. Apollo 17 EVA 3, part 1. This map continues in Figure 309.

The crew were woken for the start of the third day on the surface and soon moved into preparations for a demanding EVA, with Gordon Fullerton as CapCom. Schmitt wrote down some potential liftoff times and Fullerton gave them some world news, sport results and weather in Houston. The crew passed on some medical information, including on their hands and nails which became painful after working in the lunar gloves for long periods. Fullerton mentioned that the Command Module orbit was not being affected by mascons (mass concentrations formed by deep lava masses in the circular impact basins) as much as they had predicted.

After eating breakfast Bob Parker (who had taken over from Fullarton) relayed some plans for EVA 3. It would drop Station 10b (Figure 307) to allow more flexibility elsewhere. Station 10b to some extent duplicated what Station 5 had accomplished, sampling the basalts underneath the valley floor material. It was so named because an earlier Station 10 at this location had been split into 10A and 10B during earlier mission planning (Figure 289D). If time permitted a double core or a trench might be possible close to the LM. Parker also asked if the charge deployed near the ALSEP on the way back to the LM, EP-8, was closer to the ALSEP than EP-4 or in a depression, as there was some concern that the charge might damage the ALSEP. Schmitt said he wanted to emphasize sampling 'exotic-looking' fragments and to sample a range of rock types on the North Massif. Cernan was using a small telescope ('monocular') to look at the explosive charges near the ALSEP and said he thought the later charge was more distant, which was not correct, but judging distances was very difficult. Fullarton took over as CapCom again as Parker spoke to the scientists in the Backroom, and the astronauts began the long process of donning their cooling garments and suits.

When they were in their suits Schmitt read out numbers from their radiation dosimeters and other values. Parker came back on the radio as they put on their PLSS backpacks. Schmitt's PLSS hit a control for the steerable radio antenna on the LM, moving it off Earth-pointing and leaving Houston with a very weak signal, but it was soon corrected. They checked the suit communications links and other systems, then put on the helmets and gloves. Finally, a pressure check confirmed everything was ready for the EVA and the cabin was depressurized.

They opened the hatch and Cernan clambered out, taking a jettison bag of unwanted items and an equipment transfer bag out. He reached the footpad and turned on the traverse gravimeter. As Schmitt prepared to leave the cabin Cernan noted that the higher Sun made looking to the east more feasible. He moved to the rover to read out the SEP receiver temperature and change the battery in the LCRU. Schmitt joined him on the surface and each astronaut deployed the other's suit antenna. The rover TV was turned on and Cernan checked the rover battery temperatures and set about readying it for the traverse. Schmitt took another landing site panorama, this one west of the LM (Figure 295). Cernan read out the gravimeter values and Schmitt retrieved the Cosmic Ray Experiment which had been placed on one of the LM landing leg struts during EVA 1 and put it in a bag. This was done to avoid contamination of its results by a solar flare, and ended its operation. He then collected Explosive Package 5 from its storage place on one of the LM footpads and put it on the rover under his seat.

The astronauts took each others' pictures with the flag. Schmitt then walked over to the SEP transmitter to check that the tape repair of the solar panels was still effective. Cernan read out some rover data to Houston, then drove the rover out to meet Schmitt who was collecting a fine-grained rock sample near the SEP. He parked and reset the rover navigation system, and asked Parker where they were supposed to stop for the first rover sample. Schmitt jumped onto the rover and they set off, but veered too close to the SEP line and Cernan made a small counter-clockwise loop to get back to a safe distance from it. They were driving north to get around the end of the SEP line, but Cernan noted they could not go far beyond the line because of a large shallow depression. He initially mistook it for Rudolph but Schmitt noted it was too big. They passed the tip of the antenna line and turned northeast to bypass the depression. Schmitt gave a geological commentary as they passed some rocks and small craters and looked up at North Massif and the prominent boulder tracks on its slope.

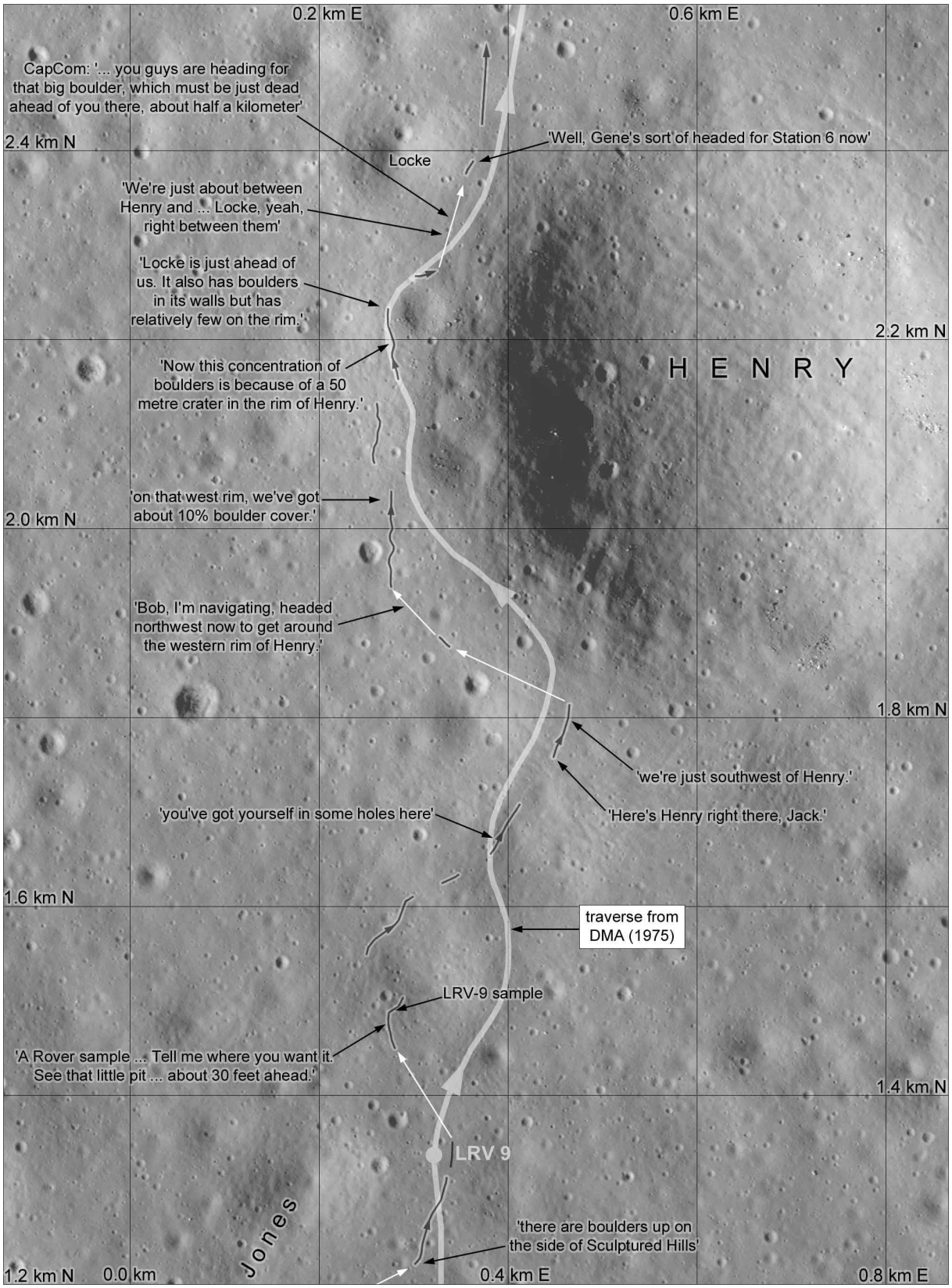


Figure 309. Apollo 17 EVA 3, part 2. This map continues in Figure 310.

Schmitt noted a crater to their right and thought it might be Jones, but it was not. Cernan noted the 'wrinkled face' of the Sculptured Hills at one point when they turned east, much closer to Jones (Figure 308), and Schmitt noted boulders up on the slopes of the Hills. The rover navigation system values placed them at the location intended for a rover sample (1.5 km north of the LM at a bearing back to the LM of 185° (clockwise from north). Cernan approached a small crater, directed by Schmitt, and stopped for Schmitt to collect the regolith sample. They moved on, looking for the large crater Henry ahead of them. Parker gave them a bearing and range for a large boulder ahead of them which marked the place where they would turn towards Station 6 at the North Massif. Now they saw Henry and turned left to skirt its western rim.

Schmitt looked ahead and saw the rock they would turn at, calling it 'the turning boulder'. It is now known as Turning Point Rock. Schmitt kept up his commentary about rock populations along the crater rim and they tried to identify Locke, where Cernan drove between Locke and Henry. Cernan decided to stop at Turning Point Rock to get a navigation fix on its location, and Schmitt noted that the big rock was split into two pieces. Cernan drove around its west side, then north of it, and gave a bearing and distance. He stopped where Schmitt could collect rock chips apparently from the 7 m tall boulder (LRV 10 in Figure 310), then drove a loop just north of the rock to face it head-on for better photography (Figure 315).

Leaving the rock, they drove to Station 6, easily visible as a large broken rock at the bottom of a prominent somewhat diagonal boulder trail. The large boulder was now broken into five big fragments, and its trail indicated the source region of the rock high on the hillside. After the mission this was named Split Boulder. During the approach to the station Schmitt was on the downhill side of the tilted rover and feeling precarious, as Irwin had on Apollo 15's EVA 2. At the station Cernan approached the west side of the rock looking for a level parking spot, but Schmitt pointed out that the rover television view of the rock would be of its shaded side. Cernan drove a counterclockwise loop and approached the rock further downslope, parking facing slightly south of east as directed by Parker for thermal control. That orientation made climbing off the rover difficult for both astronauts, Cernan going uphill and Schmitt downhill.

Cernan read out some rover data and Schmitt assessed the large broken boulder and its track, leading a third of the way up the slope of North Massif to its point of origin. Cernan turned the TV on and wondered aloud if the gravimeter would give good results on the slope. Schmitt described vesicles in the boulder and an overhang on the north side where they could collect shaded regolith. Cernan dusted the SEP, opened its cover and left it turned off, and Schmitt moved northwest to take a panorama. He found a level spot on the rim of a small crater north of the rover (Figure 316). Parker asked Cernan to lift the gravimeter off the rover and place it on the ground nearby to make it more level for the reading, and it was deployed behind the rover and prepared.

Parker noticed from the TV picture that Schmitt has raised his visor and suggested he lower it again, but Schmitt said it was scratched so much that it was difficult to see through. He was standing in the boulder track, taking a sample of regolith as Cernan approached to join him in sampling. They moved to the gap between the main sections of the rock where Schmitt took a regolith sample before it was disturbed by their feet. Cernan squeezed past him (the gap was about 1.3 m wide) and Schmitt collected a shaded regolith sample from the gap, then a sample from the illuminated area. They both began sampling the boulder now, breaking pieces off it with their hammers. Cernan took a flightline stereo panorama (a series of stereoscopic pairs of images taken side by side) along the rock face.

Parker asked them to see if there were different rock types among the boulders here, and the astronauts discussed the rocks and began sampling them. The large boulder consisted of different sections with different colours and textures, and they tried to collect samples from the different rock types. Charlie Duke was in Mission Control in Houston and said the boulder looked like House Rock on North Ray crater, but Schmitt thought it was more crystalline, not a breccia like House Rock. Cernan now collected a sample of loose material on a nearly level portion of the uppermost section of the boulder, now sometimes called Tracy's Rock (Figure 320) because Apollo 12 astronaut and space artist Alan Bean later painted a picture of the rock. It showed Cernan’s daughter Tracy’s name written in the dust on the rock, an idea Cernan had regretted not thinking of while he was there according to the Apollo Lunar Surface Journal. Core and rake samples and numerous rock samples were collected here.

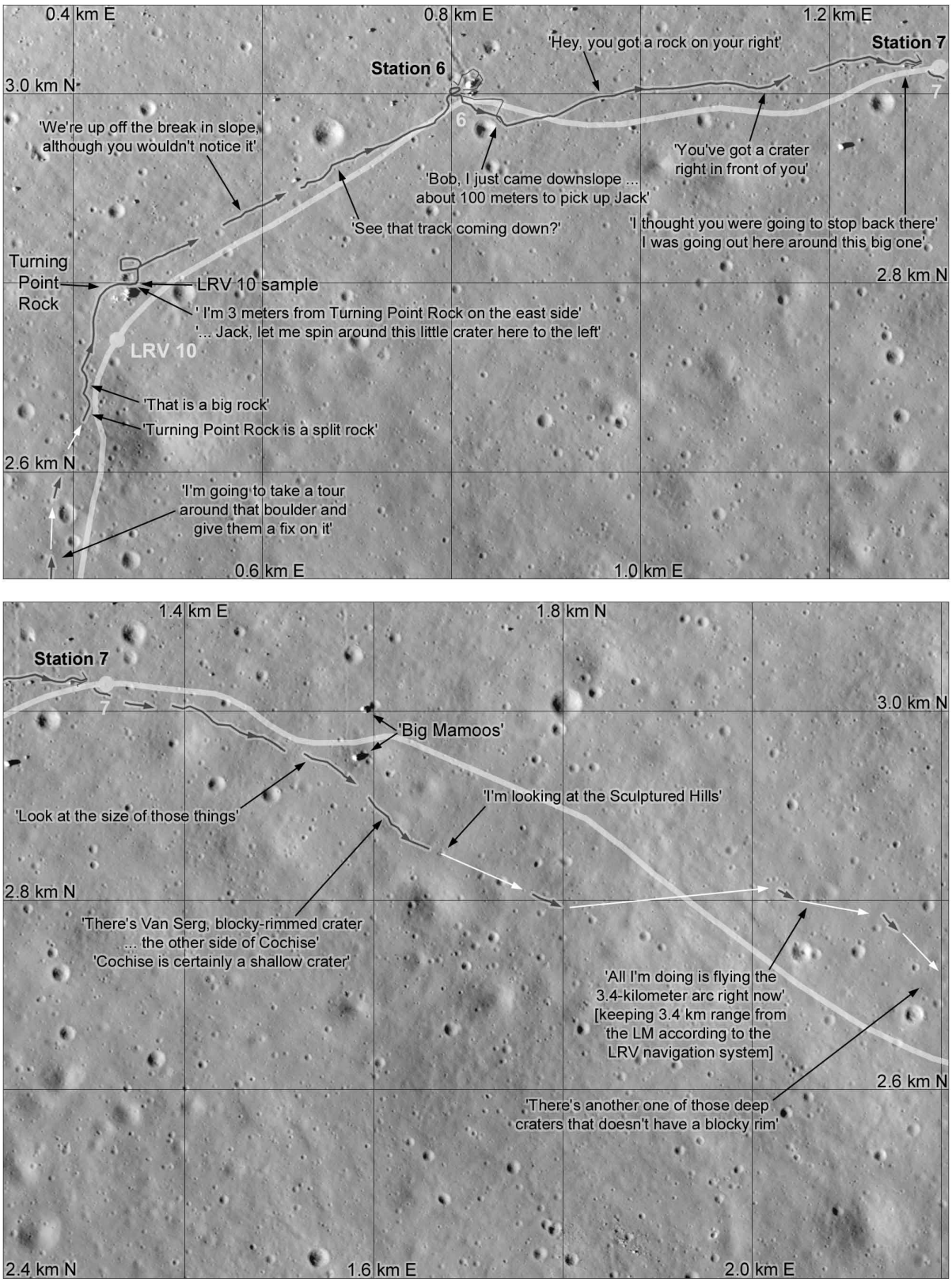


Figure 310. Apollo 17, EVA 3, part 3. This map continues in Figure 311.

Parker now suggested it was time to move on, and they should find an area near a crater below them on the slope for a rake sample and one or two cores. Cernan moved uphill a little, despite their difficulty in moving upslope, to take a second panorama while standing in a small crater. Schmitt now took a rake sample and Cernan came down and across the hill to help him, stumbling in the process. Schmitt emptied the rake into a bag Cernan held for him, a good example of the way they worked together while sampling. Next, Cernan took a core sample while Schmitt used the 500 mm lens to photograph rocks high on North Massif, the LM 3 km from them in the valley and rocks on South Massif, leaning against the boulder to take pictures uphill.

Returning to the rover, Cernan noted two tires were dented, but the wire mesh wheels stood up very well to the difficult terrain. Then Cernan read the gravimeter values as Schmitt took a few last pictures of the boulders. They stowed samples and equipment on the rover, and Schmitt decided to walk down the hill because mounting it on its downhill side would be difficult. Cernan drove down to meet him where climbing aboard would be easier. Schmitt mounted the rover and they set off along the slope to Station 7, which would be a short stop at any cluster of boulders which looked interesting. Cernan found a relatively level spot (Figures 310, 316) near several smaller rocks and dusted parts of the rover while Schmitt took a preliminary panorama, concentrating on the foreground rather than the horizon.

Parker was concerned about the amount of time Schmitt spent with his gold visor up. Sometimes Schmitt chose a half-open position so his eyes were mostly shaded but his view of the immediate foreground was clearer. The astronauts collected rocks quickly and Cernan moved over to the largest boulder in the area to document it with another flightline stereo sequence. They both worked to sample the boulder and then Cernan collected a football-sized rock. Parker asked Cernan to finish at the station by taking a second panorama, which he did while standing in a little crater whose downhill side was nearly horizontal. They returned to the rover and Cernan read out the battery temperature.

They mounted the rover and set off, communicating via the distant LM rather than directly because the rover's communication unit was turned off to let it cool. They drove down the slope diagonally with Schmitt on the downhill side as usual, and saw two large rocks ahead of them which Cernan called 'big mamas, mamoos' (likening them to breasts). The rover passed south of the rocks and they noticed Van Serg crater and the 'old man wrinkled face' texture of the Sulptured Hills. Schmitt noted that he could feel the warmth of the Sun more now than earlier in the mission, and both astronauts continued making geological observations. They arrived at the western rim of SWP and Cernan drove around its southern rim, noting that its eastern side was continuous with the slope of the Sculptured Hills.

Parker reminded them that the Station 8 location was very flexible and they could choose anywhere that looked suitable. On the flight plan maps Station 8 could have been located anywhere along the base of the hills. The actual location saved travel time. Schmitt had to be reminded to keep taking pictures during the drive, and soon he saw a c. 30 m diameter crater with many blocks on its rim but a darker appearance than most fresh craters. He suggested a rover sample (LRV 11, Figure 311) and they stopped on its eastern side. The blocks turned out to be crumbly regolith breccias (fused by the heat and shock of impact in deep regolith) or 'instant rock'. They now aimed for a rock on the slope of the Sculptured Hills which would be Station 8. Cernan found a fairly level parking spot and stopped, immediately reading out rover values to Houston.

Parker advised which parts of the rover needed dusting and Cernan followed his instructions. He prepared the TGE for another reading while Schmitt looked at rocks. The repaired fender had slipped out of one of its clips and Cernan noted he would have to fix the clip before they moved on. Schmitt was hopping like a kangaroo to climb the slope, aiming for a distinctive 70 cm diameter glass-coated rock, the only one sitting on the surface rather than largely buried. He documented it with photographs and then stood on its uphill side and pushed it with one foot. It rolled downhill briefly and he pushed it again. This time it rolled into a small crater and stopped. Cernan had been collecting samples from a rock and now he walked up to the rolled boulder. Schmitt collected some regolith from under the rock's original position and Cernan hammered samples off the rock. They fell off it and he lost sight of one and had to walk over to pick up another. After sampling it Cernan pushed it with his hand and it rolled another 2 m down the hill. He chipped part of the glass coating off it and put it in a sample bag.

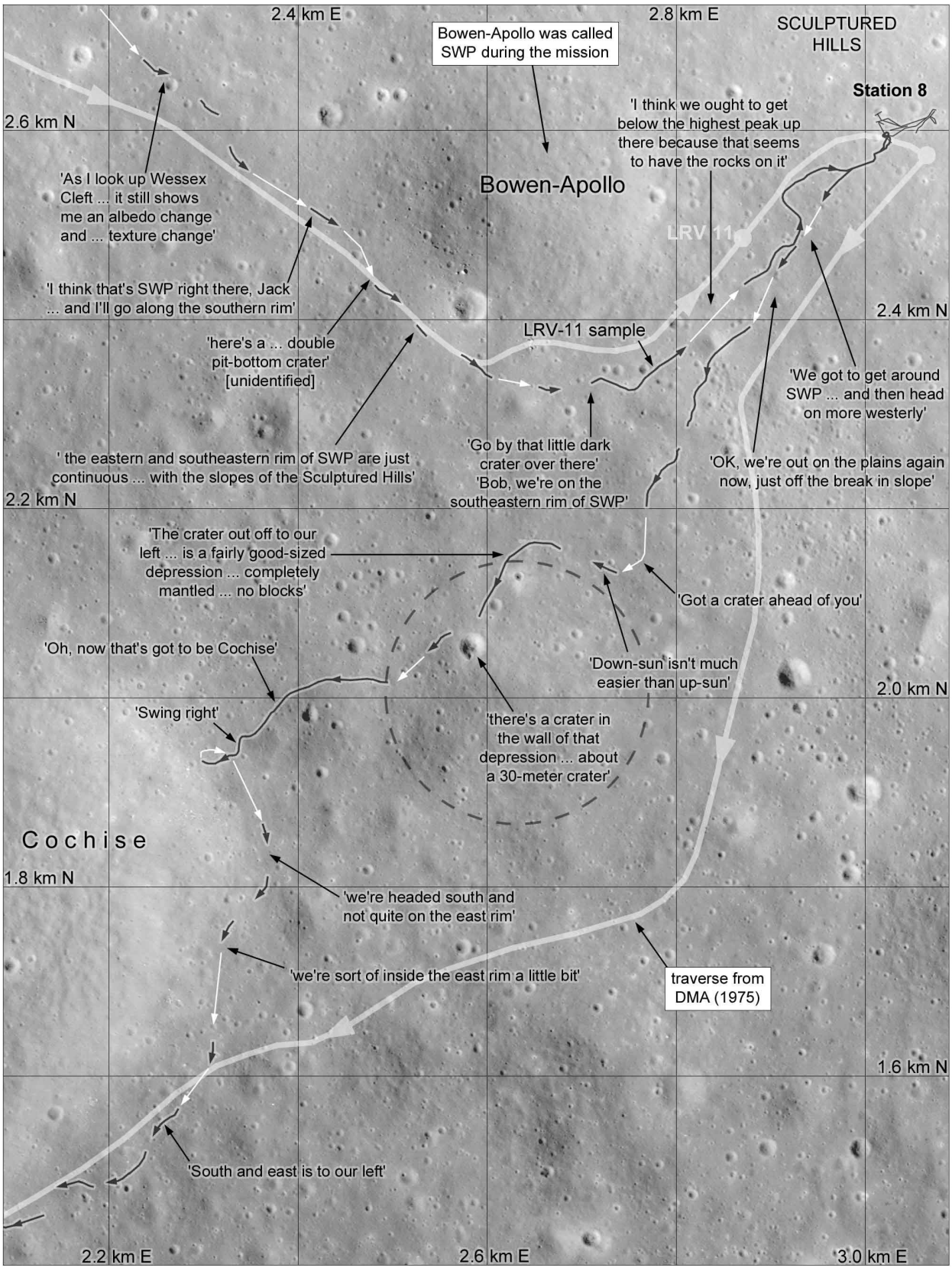


Figure 311. Apollo 17, EVA 3, part 4. This map continues in Figure 312.

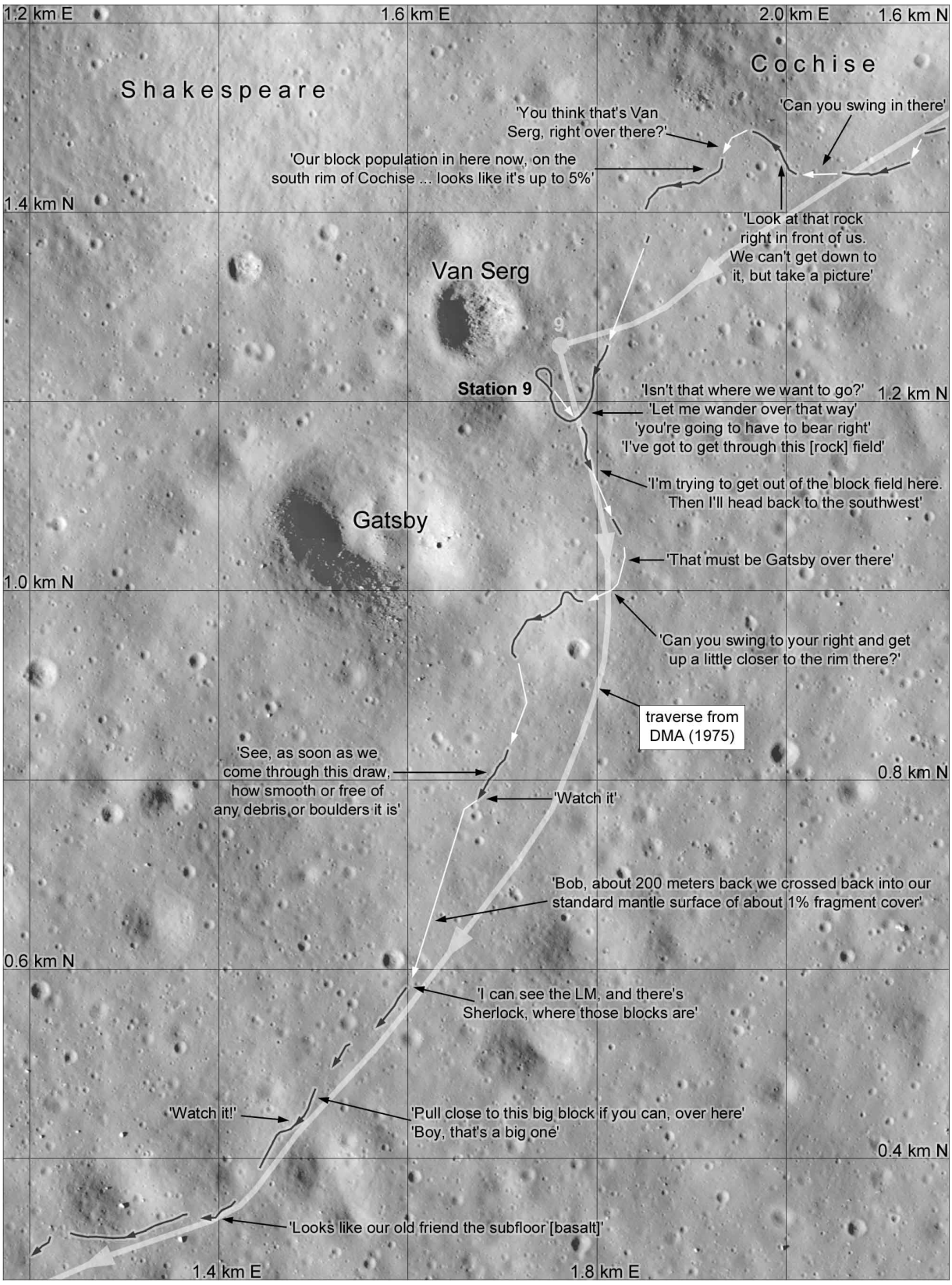


Figure 312. Apollo 17, EVA 3, part 5. This map continues in Figure 313.

The next step was to collect a rake sample. Schmitt moved over to the rim of a crater just north of the rover, imitating a skier, while Cernan took pictures for a panorama. He could see the LM over Cochise crater. Schmitt collected the rake sample and Cernan joined him and picked up a sample inside the crater. They also took a 1 kg sample of regolith here and Schmitt documented the site with a flightline set of stereoscopic image pairs. Cernan returned to the rover, read out the gravimeter numbers and placed the instrument on the ground for a second reading. He then set about repairing the fender, which had slipped out of one of its clips. Schmitt dug a trench and took samples from different depths in the trench wall, assisted by Cernan in the bagging of the samples.

A final panorama was taken by Schmitt as Cernan readied the rover for departure, including giving another gravimeter reading and picking up two sample bags Schmitt had dropped. Schmitt dropped and retrieved a third bag. Their sample container was overflowing, but now they got everything safely on the rover. As Cernan stowed the samples, Schmitt read out the SEP temperature. The SEP experiment was not working properly, though it did collect some data during EVA 2. Cernan fell as he tried to climb onto the rover. Schmitt said 'You got your pockets completely filled with dirt' and Cernan said it was an extra sample, but this was a sign of how dirty they were getting and how much dust was and would be a concern in lunar exploration.

Cernan began driving away from Station 8, beginning by making a clockwise turn to follow their tracks downslope. Now Cernan found himself temporarily on the downhill side of the tilted rover, as Schmitt had been on many occasions. He turned again and they looked ahead, with some confusion between the crater called SWP after the Science Working Panel (the group who helped plan activities at the landing site, as in Figure 289) and another crater called Bowen nearby. After the mission SWP was renamed Bowen (Figures 291A, 307). Soon they were off the slope of the massif and back on the rolling but fairly level valley floor, noting that the makeshift fender had come loose again and the rear wheel was throwing dust over the rover.

Cernan turned to the right to bypass a large shallow depression. Contemporary maps showed the rover path running south of this crater but in fact they drove north of it, about 400 m from the route in older maps. For a short time they were driving directly away from the Sun, which proved as difficult as driving towards it because of a lack of visible shadows. Schmitt noted that the depression had no concentration of blocks on its rim, though he saw a large block on the rim of a 30 m crater inside the depression. They dipped down into the depression briefly, then emerged to see Cochise in front of them. Cernan approached the rim so Schmitt could see and photograph the crater. Schmitt described the view and the valley floor stratigraphy visible in the inner wall of Cochise, and then Cernan looped clockwise and drove south along the crater rim. Parker asked for a bearing and range and Cernan read them out.

Schmitt kept up his commentary on geology and as they turned onto the southern rim of Cochise he asked Cernan to give him a view into the crater, noting an interesting rock a little too far into the crater for them to reach. Then they turned south to reach Van Serg and Cernan drove to the point shown by the navigation system which Parker was suggesting for Station 9. The surface was very blocky and Cernan had to pick his way carefully on the rover to reach the indicated point, where he stopped and they dismounted. Van Serg crater was named by Schmitt after the pen name of Hugh McKinstry, a professor at Harvard University who himself took the name from a Harvard building. According to the Harvard website in 2024, 'The site is named after an acronym for its early Harvard tenants: Veterans Affairs, Naval Science, Electronic Research, Graduate dining hall'.

Schmitt said the crater looked like a typical fresh impact crater. Then he brushed the SEP instrument clean and tried to create some lengthwise creases in the fender to stop it curling. Cernan read out rover numbers and Parker advised they wanted a radial sample here, sampling from different points along a radius from the crater outwards. Parker also noted that the SEP seemed irretrievable. Cernan set up the gravimeter as Schmitt walked over to the rim of Van Serg, peered in, described it and took pictures of the rock-strewn crater rim and interior and locator images of the rover. Cernan joined him and they collected samples including one breccia which was too big to fit in a bag. To identify it later they tried to pull a bag over one end and stow it with the bag under it to keep it loosely attached.

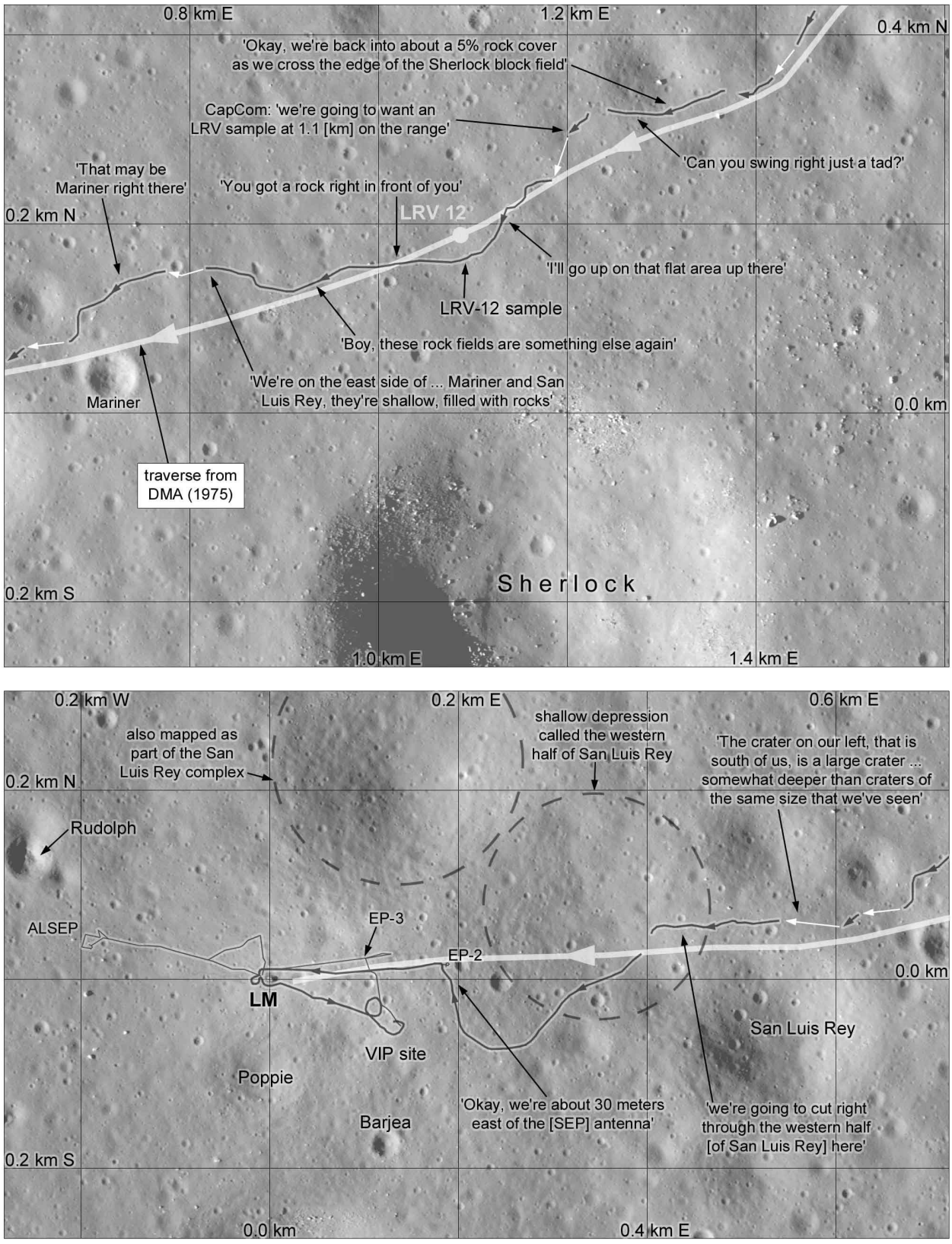


Figure 313. Apollo 17, EVA 3, part 6.

Schmitt now collected regolith samples and described the rocky central mound of Van Serg to Parker. Cernan picked up a glass-covered rock and told Parker they were kicking up small glass beads in the regolith. They sampled some of them and then each took a panorama which would combine to give stereoscopic coverage of the site. Cernan's panorama was halted when he ran out of film. Schmitt collected a set of samples radial to the crater while Cernan took some 500 mm images of North Massif. To do that Cernan had to return to the rover and while there he took a Traverse Gravimeter reading before lifting the gravimeter off the rover to take a second measurement with it on the ground. Then he took the telephoto images of North Massif to show boulder tracks and outcrops.

Schmitt's radial sampling was complicated by the scoop, which would not stay on his handle, so the ground science team suggested he abandon the effort. Cernan read out the new gravimeter reading as Schmitt collected regolith samples near the rover, making a small trench which revealed a light-toned layer under the darker surface. Parker had been urging the crew to move on but the new sampling put them behind schedule so much that the ground team decided to drop Station 10 altogether. They now wanted a double core to explore the stratigraphy here but Schmitt thought the rocky regolith would not permit it. Cernan hammered one core into the ground, then a second, and stowed the capped core on the rover. Schmitt put out an explosive package and took a second panorama, which included a view of one of their empty sample bags on the floor of Van Serg. Finally the tired astronauts collected a large rock and mounted the rover. One brief misunderstanding occurred before they left. The rover TV showed an unexpected orange patch against a background hill and Parker asked them what it was. It might have been another patch of the orange soil seen at Shorty, but they soon realized it was the orange flag on the newly-deployed explosive charge, badly out of focus.

Cernan drove away and headed for the LM, maneuvering to get out of the block field around Van Serg. Schmitt noted the crater Gatsby as they passed it, and asked Cernan to turn right for a better view of it. He thought the dark mantling material of the valley floor was superimposed over Gatsby's very rocky southwestern rim. They were about 200 m from the rim as he said that and Cernan meandered west to within 100 m of it before turning south again ino a very smooth area. Parker suggested they drive a little south of a direct path to the LM to avoid rough topography around San Luis Rey, but Cernan was already heading in that direction.

Schmitt pointed out the block field around Sherlock where Station 10 would have been, and as they approached he noted a prominent large boulder and asked to pull in close to it. It was a vesicular basalt probably excavated from the 'subfloor', the lava flow under the regolith, by the impact which formed Sherlock or another crater. Schmitt photographed the rock and the dark regolith or mantle material which partly covered it. They turned south and then west again, stopping at their closest approach to Sherlock for a rover sample. Schmitt directed Cernan to an appropriate spot and collected the sample, and they resumed their westward path. Cernan saw Mariner and San Luis Rey craters and the many rocks around and in them. He steered around Mariner on its northern side, then out onto a ridge between San Luis Rey and the shallow depressions on its northern side.

San Luis Rey is shown as a single crater in Figure 307, but the crew carried maps showing the name applied to a string of depressions in this area, less clearly seen in the Apollo 15 images they were based on. It extended from the large shallow crater north of the SEP (called Mariner before the mission) to San Luis Rey as mapped here (Figure 313). Cernan referred to it as 'the San Luis Rey complex' and pointed out that they were 'going to cut right through the western half here' as they entered a broad shallow depression, really the middle part of the 'complex'. He turned south to avoid its low central region, and soon after leaving the depression by its southern rim he swung north again to regain his course. When due east of the LM at a range of just less than 200 m he stopped and Schmitt stepped off the rover to deploy Explosive Charge 2. He noticed the gate on the back of the rover was open but did not see that several sampling tools (rake, scoop and two extension handles) had fallen out. He pulled the pins to prepare the charge and set it down in a small depression, then took an image to help locate it.

Cernan drove closer to the SEP, which was now inoperable, and Schmitt directed him to a rock which he (Schmitt) had seen earlier and wanted to collect, half way from the SEP to the LM. He climbed off the rover again to pick up the rock and accidentally kicked it under the rover, but retrieved it and put it in a sample bag on the rover. Cernan drove back to the LM to unload the rover as Schmitt walked back, and Parker updated them on plans for the final activities of the EVA.

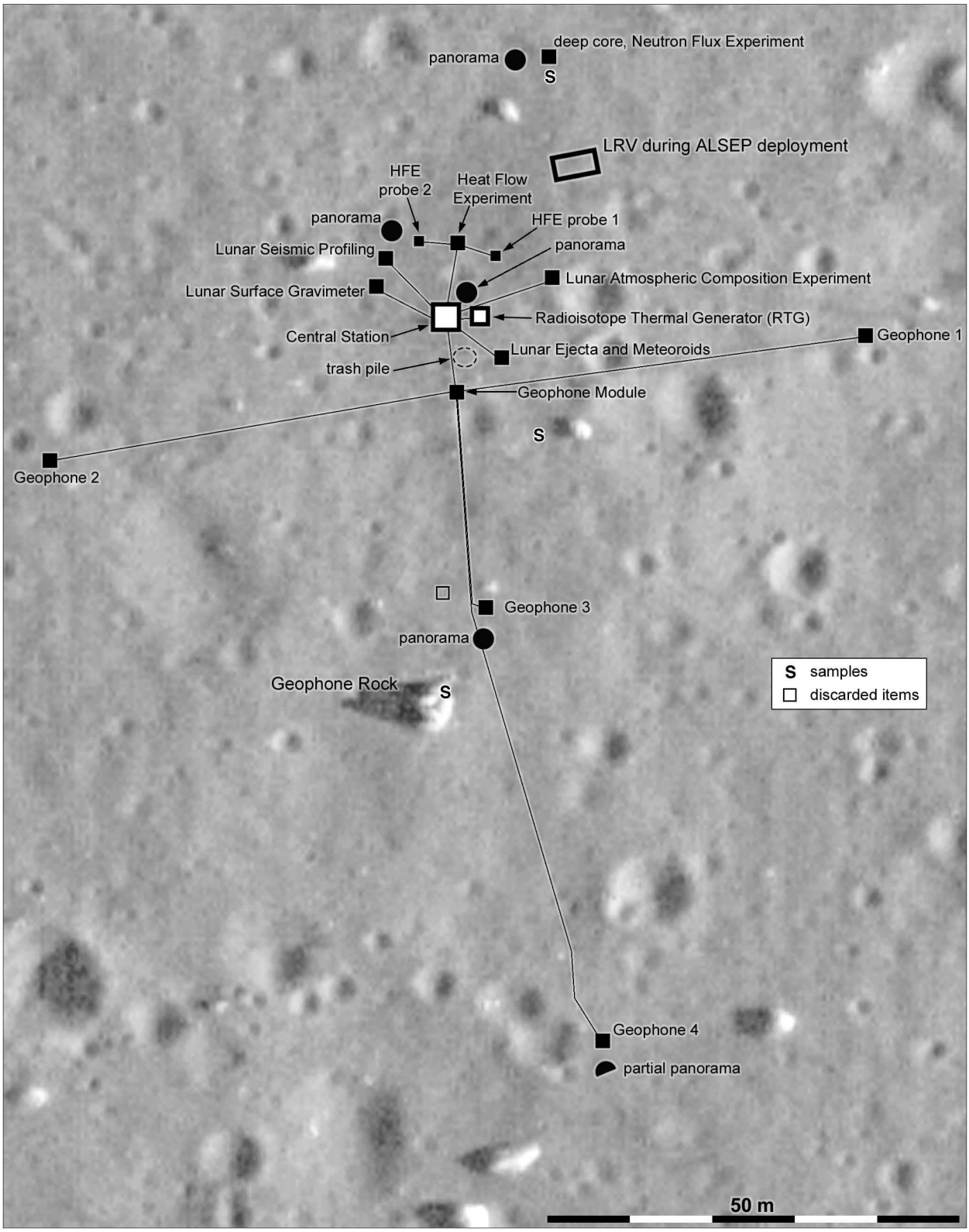


Figure 314. Apollo 17 ALSEP layout.

Schmitt began stowing the core tubes in a bag and left it on the LM footpad under the ladder. Schmitt was supposed to collect a regolith sample near the base of the LM just inside the eastern (rear) footpad which could be tested for contamination from the landing rocket plume, and he was surprised to find he had no rake or scoop on the rover. They had fallen out earlier. He used the rover sampling scoop instead and the possibly contaminated regolith was stored in a special environmental sample container (SESC), which protected the sample from contamination back on Earth. Then he documented the sampling site with photographs, noting that the 'before' images had been taken on EVA 1 when the Cosmic Ray experiment was attached to the LM leg.

Parker asked to be kept up to date with the locations of various sample bags and other items as they came off the rover to help ensure nothing got left behind. Cernan set the gravimeter on the ground and prepared it for a measurement. He noted that a clamp had fallen off the repaired fender, probably after Station 9. Parker also gave some revised instructions on using the cameras, including bringing both Hasselblad cameras back rather than leaving one on the rover seat for a potential long term exposure study after a future mission to collect it. Now Cernan moved east of the LM and photographed the site and equipment, including a view of Earth above the LM.

Schmitt took the Equipment Transfer Bag (ETB) from the MESA to the rover. The Cosmic Ray Experiment was already in the bag, having been put here early in EVA 3 to protect it from a predicted solar storm event, not serious enough to affect the crew but enough to compromise the readings. Cernan read out the latest gravimeter reading and set it to take a calibration reading. The astronauts helped each other remove their tool harnesses. They soon followed that with a brief ceremony, planned by the crew but not on the official plan. Cernan spoke to young people across America and the world, pointing out a rock Schmitt was holding, a breccia composed of fragments of different types of rock (this was how he characterized it, but in fact they did not have a suitable breccia and used a chunk of basalt instead). Schmitt handed it to Cernan who said that they hoped it would serve as a symbol for all people that they could live in peace and harmony in future. Schmitt added that pieces of it would be distributed around the world, and this was done as promised. Nearly 500 pieces of the 'Goodwill Rock' were sent out for this purpose.

A second part of this ceremony was rover TV coverage of the plaque on the LM leg just behind the ladder. The plaque, signed the the astronauts and by President Nixon, said "Here man completed his first exploration of the Moon, December 1972 A.D. May the spirit of peace in which we came be reflected in the lives of all mankind". NASA Administrator James Fletcher came on the radio to offer congratulations and wishes for a safe return to Earth.

The Traverse Gravimeter was no longer needed and Cernan threw it out about 25 m to the southwest where it hit the surface and bounced, leaving prominent marks (Figure 295). Then he prepared to drive the rover out to its final VIP parking spot near the SEP. He drove out a little south of east, then turned counterclockwise to face the lander, but was dissatisfied with the position, looped back and mover further out before turning again and parking facing the LM (Figure 316). Meanwhile Schmitt walked out to the ALSEP and followed instructions from Houston on tapping the Lunar Surface Gravimeter and checking the level indicator. Then he took images as directed to document the Central Station and used a tool to push regolith away from its south side, where it was overheating. He also slightly adjusted the Station to level it better. The gravimeter was still not operating properly and he had to return to it and tap it again, then rock it side to side with the UHT. Finally he took more documentation photographs of the heat flow probes, the LMS (later referred to as LACE, Lunar Atmospheric Composition Experiment) and the neutron flux probe, which also needed an adjustment.

Cernan removed the replacement fender and part of the left rear fender and brought them back to Earth, where the first is on dispay at the Smithsonian National Air and Space Museum in Washington, D.C. He turned the high gain antenna towards Earth so the river could transmit video during the LM liftoff and dusted the rover to reduce overheating. He had to adjust the antenna again, having difficulty aiming it at Earth because of the orientation of the rover. He checked nothing was left on the rover accidentally. He intended to place Schmitt's camera between the seats as a test of lunar environmental degradation if it was ever collected in future, but the camera made its way back to the LM and it was probably only the 500 mm telephoto lens which was left on the rover. Cernan later wrote that he scratched his daughter Tracy's initials in the surface near the LRV, but there is no indication in the transcript of this happening and it could represent confusion with the Tracy's Rock story.

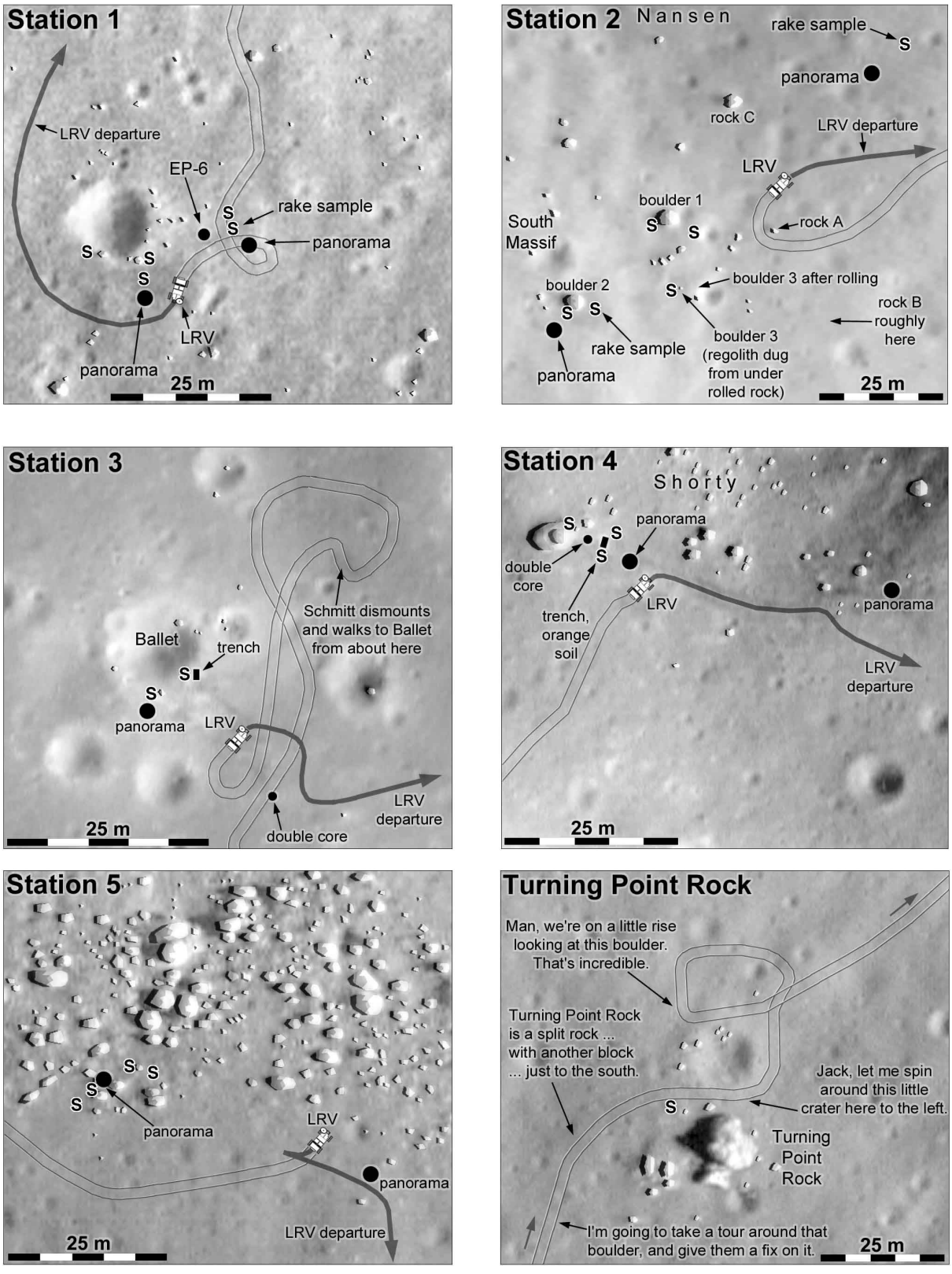


Figure 315. Plans of Apollo 17 science stations 1-5 and Turning Point Rock. The LRV is not to scale but is roughly correctly sized at Station 3. Track widths are not to scale.

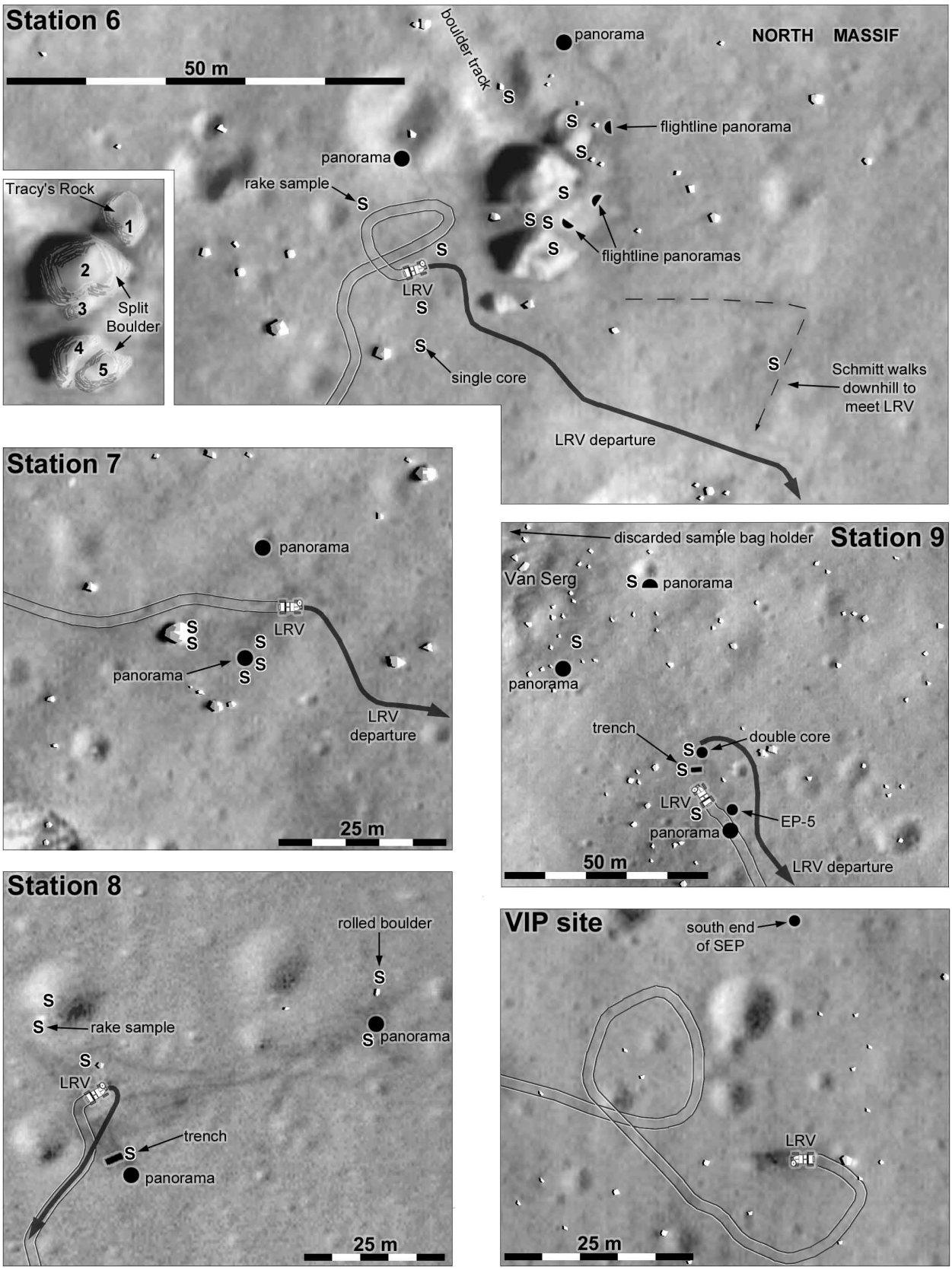


Figure 316. Plans of Apollo 17 science stations 6-9 and the rover VIP site.

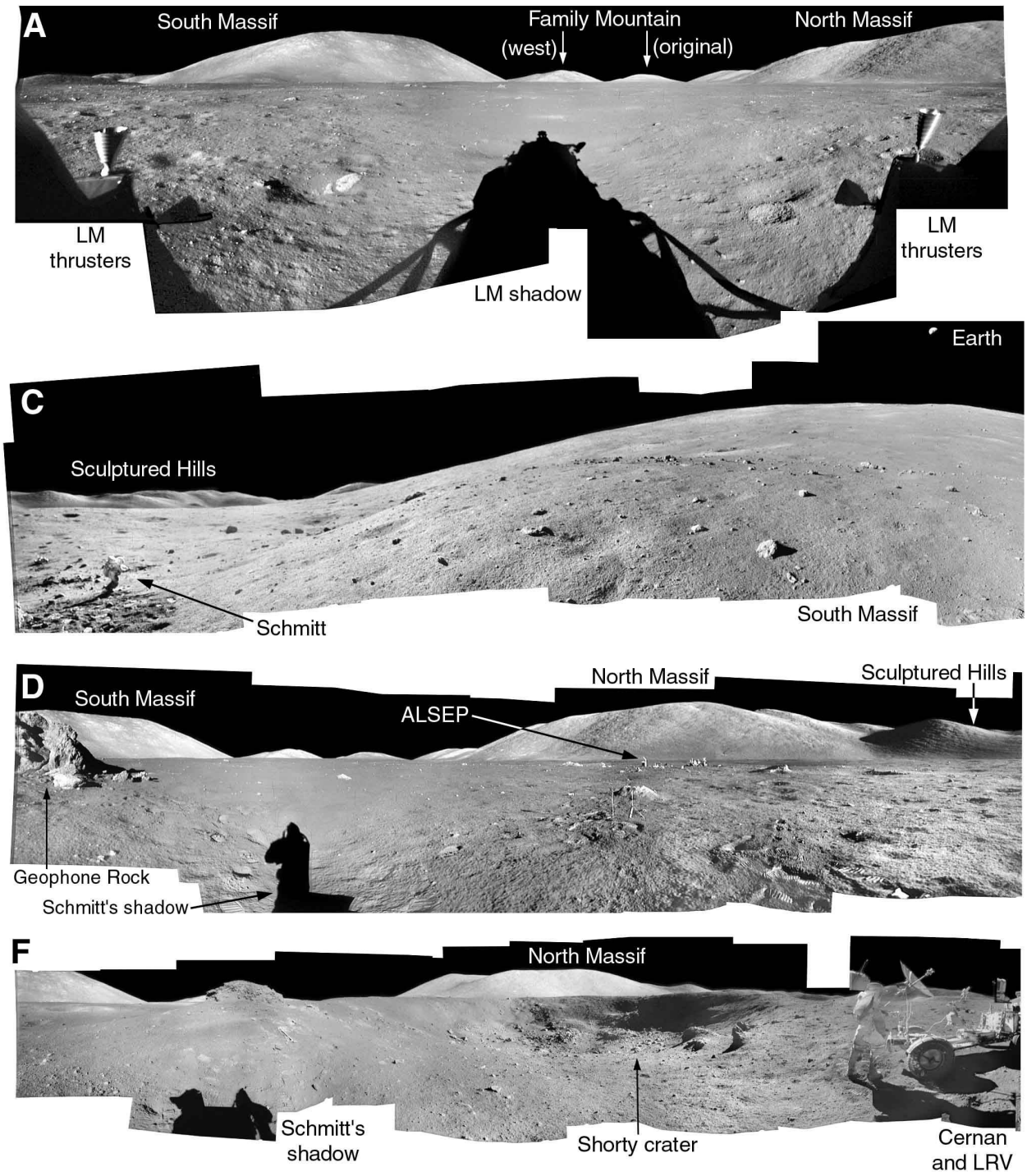
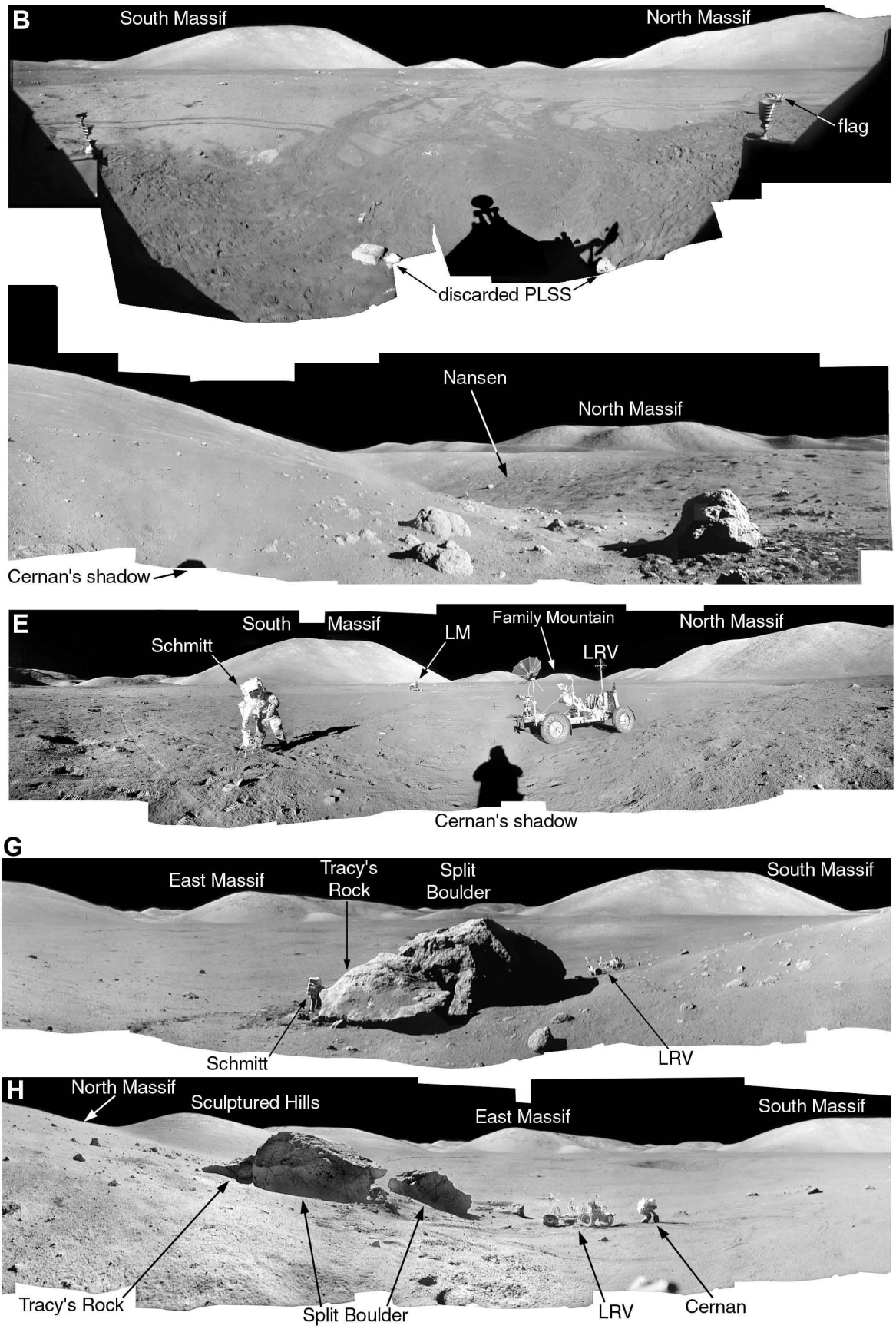


Figure 317 (both pages): Apollo 17 panorama, assembled by P. Stooke. A: view from the LM windows just after landing. B: LM window view after EVA 3. C (across both pages): Station 2. D: south of the ALSEP. E: Schmitt at the SEP transmitter. F: Station 4 at Shorty crater. G, H: Station 6 boulders.


B
South Massif
North Massif
flag
discarded PLSS
Nansen
North Massif
Cernan's shadow
E
South
Massif
Schmitt
LM
Family Mountain
LRV
North Massif
Cernan's shadow
G
East Massif
Tracy's
Rock
Split
Boulder
South Massif
Schmitt
LRV
H
North Massif
Sculptured Hills
East Massif
South Massif
Tracy's Rock
Split Boulder
LRV
Cernan

Before Cernan returned to the LM he thanked the thousands of workers who had contributed to the success of Apollo and carried the last explosive charge out to the west end of the SEP antenna, where he deployed it. He turned the SEP transmitter off, took locator pictures of the charge and returned to the LM. Schmitt left the ALSEP and returned to the LM. His efforts with the LSG had not succeeded in releasing a balance beam inside it which could potentially detect gravity waves, and it would never achieve its potential goal.

When both astronauts were at the LM and with time running out for this last Apollo EVA, they prepared to leave. Schmitt threw a hammer out towards the ALSEP where it landed about 40 m from the LM (Figure 295). Cernan took pictures showing it in flight. They packed the ETB, including with one last core tube which Schmitt had pushed ino the ground just inside the north footpad. It was heavy and would not close properly. Schmitt started to mount the ladder, pausing so Cernan could brush dust off his boots and legs. Cernan passed up the ETB and other items and soon Schmitt climbed through the hatch into the cabin. He began stowing bags and equipment as Cernan completed his tasks on the surface.

Finally, just before climbing the ladder, Cernan said "Bob, this is Gene, and I'm on the surface; and, as I take man's last step from the surface, back home for some time to come - but we believe not too long into the future - I'd like to just [say] what I believe history will record. That America's challenge of today has forged man's destiny of tomorrow. And, as we leave the Moon at Taurus-Littrow, we leave as we came and, God willing, as we shall return, with peace and hope for all mankind. Godspeed the crew of Apollo 17". He climbed in and they maneuvered in the cramped cabin to get the hatch closed.

They turned their PLSS water controls off, Gene helping Schmitt because he could reach the controls more easily. They pressurized the cabin and took off their gloves, commenting on the amount of dust on everything. The PLSS functions, air, water and communications, had to be transferred to the LM so the cabin could be depressurized again for the PLSS and other items to be discarded through the hatch. As they worked on this, Bob Overmyer, the CSM CapCom, came on the radio to report that all was well in orbit, and that Ron Evans had been looking at Shorty crater to see if he could see any colour variations. One of his comments had been "I've got Shorty in the picture. It looks like a sharper crater than any of them in the pentagon complex. The other one that looks sharp, just like that one, is F crater." The identity of F crater is not known, but it might possibly be one just west of Victory and about half the size of Shorty. The 'pentagon complex' is also not identified, but two possible interpretations of it are shown in Figure 257.

The astronauts discarded their PLSS units and then weighed the sample bags, reading out the weights so the ground team could calculate liftoff mass and if necessary select some samples to discard with the PLSS units. The mass was acceptable, so now they prepared all the items they would jettison and put their gloves back on. After a pressure safety check they opened the hatch and threw out their PLSSs and an unused pair of EVA gloves before closing the hatch and repressurizing the cabin. Now they could remove the bulky suits and helmets. They had a chance to talk to Charlie Duke, who with John Young formed the backup crew for the mission.

Then another voice came on the radio, that of Deke Slayton. The CSM had been placed in an orbit which was expected to evolve under the influence of mascons so it would be in the desired rendezvous orbit after the LM ascent stage launched. Mascons were still not well mapped and the prediction was wrong. so the CSM had to make an orbit adjustment to bring it to the optimal orbit. Slayton pointed out that if it failed to do so the LM would have to change orbits itself, requiring more fuel, and that might not allow a full set of samples to be returned. Schmitt suggested that he and Cernan had lost enough weight during the mission to make discarding samples unnecessary.

Parker now handed CapCom duties over to Apollo 16 astronaut Ken Mattingly. Schmitt and Cernan took pictures out of the LM windows, showing the profusion of tracks around the LM, and then removed their suits. They took pictures of each other, dirty and exhausted after three hard days on the Moon but pleased with their success. Mattingley read out some updated lift-off times and Schmitt wrote them down and read them back to confirm them. This procedure was always followed and this time it caught a mistake. Then Mattingley asked several questions the backroom scientists had prepared, such as: Were the Station 6 rocks the same as those at Station 2? Schmitt thought they were similar but more altered by heat and pressure. Were the Van Serg breccias similar to the blue-gray material at Cochise? That would be possible. What was the object described as a cowpie at Van Serg? Impact-melted glass which fell on the surface while still viscous.

The astronauts were eating as they answered the questions, trying to record impressions while they were still strong. At one point Schmitt noted 'a little spurt of dust come up by the window' and suggested 'Something we threw out must have popped'. They finished eating and answering questions, and Mattingly provided some instructions on stowing samples and film magazines which would even out the weights and give them a balanced vehicle for the ride up to orbit. They tried to clean themselves and the cabin and prepared for a sleep period.

Eight hours later they woke and tried to sing 'Good morning to you' to CapCom Gordon Fullerton (to the tune of Happy Birthday') and Fullerton replied with 'Also Sprach Zarathustra', the opening music from 2001: a Space Odyssey. The astronauts were already eating breakfast by the time they contacted Houston. Cernan asked for a status update on the LM and CSM. The CSM had made a successful maneuver and was ready for them. Schmitt read out a paraphrased version of 'The Night Before Christmas'. He had read a different version up to the crew of Apollo 8 on Christmas Day, 1968.

Fullarton read up some revised instructions and the crew gave updates on their sleep and meals. They put on their bulky suits for the last depressurizaton and jettison procedure, and gathered the items to be jettisoned. Finally the helmets and gloves were put on and all the suit systems checked. They spoke briefly to Ron Evan as he passed overhead for the last time before liftoff, and then the LM cabin was depressurized. Two jettison bags were placed near the open hatch and kicked out, and the hatch was closed again only 1 minute after it was opened. The cabin was repressurized and the gloves and helmets came off again.

The LM was prepared for liftoff and the LRV camera was turned on to watch the launch. The crew put their helmets and gloves back on and Evans appeared again after passing behind the Moon since he last spoke to them. Schmitt tried to start the 16 mm camera to film the liftoff from his window, but it failed. At liftoff they lost their communication link with Earth for 4 minutes, but otherwise ascent was uneventful. Communication via the CSM was still available. The rover camera observed liftoff and followed the ascent for 26 seconds, then looked back at the descent stage and the flag, which was still standing. They reached orbit and 90 minutes after liftoff they docked with the CSM.

Soon after that, as they began to transfer their cargo to the CSM, Fullarton read out a message from President Nixon marking the end of Apollo (in his words, though the Skylab flights and the Apollo-Soyuz Test Project were still to come). It included the comment 'This may be the last time in this century that men will walk on the Moon, but space exploration will continue, the benefits of space exploration will continue, and there will be new dreams to pursue, based upon what we have learned'. The long delay was all too true, and it would be 54 years before any humans would return to the vicinity of the Moon on the Artemis 2 flight.

After unloading the LM and putting a jettison bag from the CSM in it, Challenger's ascent stage was released from the CSM. 30 minutes later a thruster burn slowed it enough to hit the surface in the vicinity of the South Massif, as described below.

The crew spent 2 more days in lunar orbit making visual observations and extending the coverage of the CSM instruments. In particular they looked for more evidence of orange material, noting its presence in the Sulpicius Gallus area, a pyroclastic deposit in southwestern Mare Serenitatis.

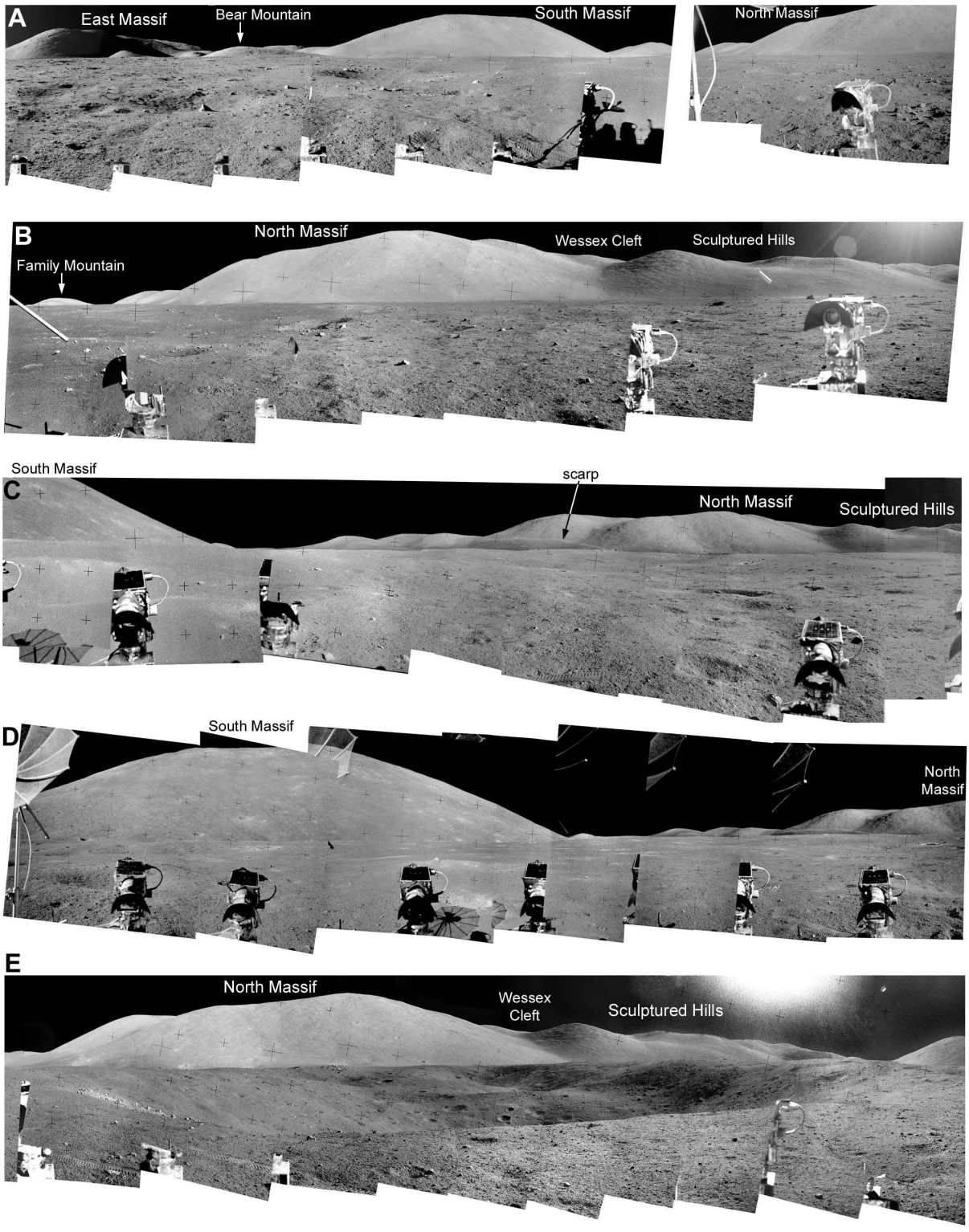


Figure 318. Apollo 17 rover panoramas (cropped). A: EP-7 site, EVA 1. B: EP-4 site, EVA 2. C: LRV panorama northeast of Station 2, EVA 2. D: Station 2a (gravimeter stop), EVA 2. E: Victory crater, EVA 2.

Long after the mission, Schmitt was still working to interpret the geology of the Taurus-Littrow Valley in papers and conference presentations. At LPSC in 2017 he introduced a new crater name to the valley, 'Fitzgibbon', saying that

his wife was looking over his shoulder while he was working and said that she hoped there was crater named after her. He obligingly called a crater Fitzgibbon (he had married Teresa Fitzgibbon in 1985). In 2017 the crater was said to be 350 m in diameter and 1000 m NNE of Shorty (Figure 291), and its ejecta had protected the orange soil at Shorty from being mixed into the regolith until Shorty formed to expose it (Schmitt, 2017). Schmitt used the same name in 2018 and 2022 for two other craters (Figure 305) immediately adjacent to Shorty and so degraded they are hard to detect, but the basic story remained the same (Schmitt, 2017; 2018; 2022).

Figure 314 is an enlarged view of the ALSEP area to show equipment layout, panorama localtions and sampling sites. The Lunar Seismic Profiling antenna transmitted the detonation signals to the emplaced explosive packages after the crew had left.

Figures 315 and 316, based on maps in Stooke (2007) as well as illustrations in Wolfe *et al*. (1981), LRO orbital images and surface panoramas, show the science stations at the Apollo 17 site, including sample locations (**S**), panorama locations (black circles), equipment and other surface activities. At Station 2, six boulders were given designations (A, B, C, 1, 2, 3). Boulders 1, 2 and 3 were sampled. The large broken boulder at Station 6 was visible in Apollo 15 orbital images, with an obvious track showing how it had rolled downhill from its source region. The largest pieces are collectively called 'Split Boulder', and the flatter northern section is now called Tracy's Rock as discussed above (Figure 316, 317). Rover tracks are shown as recorded in surface photography.

Figure 317 shows some of the Apollo 17 panoramic photography. Figure 317A is a composite view from the LM windows just after landing. The name Family Mountain has been applied to both peaks seen on the western horizon, as discussed earlier. 317B is the same view after EVA 3, showing rover tracks and the discarded PLSS life support backpacks. 317C (across both pages) is a panorama from Station 2 with Earth in the sky above South Massif. Figure 317D was taken near Geophone Rock, south of the ALSEP. 317E shows Schmitt setting up the SEP transmitter east of the LM. 317F is Station 4 at Shorty crater. The orange soil was found near the large boulder at left, just above the truncated shadow of Schmitt. The image of Cernan at right is also truncated by movement in this compilation. Figures 317G and 317H are two views of the Station 6 boulder and the surrounding hills. Figure 318 shows rover panoramas, and Figures 319 and 320 show circular projections of several panoramas including the LM window views.

After its return to orbit the LM ascent stage was unloaded, jettisoned, and deliberately crashed on the lunar surface near the landing site to provide a seismic signal. The impact would have been visible to the rover TV camera, but nothing was seen at the expected location, perhaps because the resolution was inadequate, though there was 10 to 15 km of uncertainty in the impact location. The impact was detected by the Apollo 17 geophones and ALSEP seismometers at the Apollo 12, 14, 15 and 16 sites and initial analysis suggested it probably struck the surface within about 20 km of its target. A few minutes after the impact the CSM flew over the site and Evans noticed a bright spot on top of South Massif which he did not remember from before. 'I can see a bright spot on the top of the South Massif ... if you come from the east, it's the second ridge from the east, and right on top of the ridge is a bright spot'. The most likely location of this spot is at 19.919° N, 30.380° E, which LRO images reveal to be a typical impact crater also seen in Apollo orbital images (Figure 321A).

Tracking suggested that the impact location was on the north-facing slope of the massif, not on its summit plateau (Figure 321A). Searches of this area do not reveal any obvious impact feature. Michael Marcus proposed an impact at 19.938° N, 30.498° E, but the dark feature here appears to be a shadow cast by a steep rock outcrop on the wall of a small ledge at the crest of the slope, and is visible in a 500 mm telephoto image (AS17-144-22101) taken near the LM on EVA 2, obviously before the impact (Figure 321C, E). Jim Meador (personal communications during 2024) analyzed the LM trajectory and concluded that the flight path was probably lower than expected and the impact may have occurred on the floor of the valley or the eastern side of Bear Mountain, though impacts on the slope of South Massif were not ruled out. Searches of the area have not produced a candidate impact site.

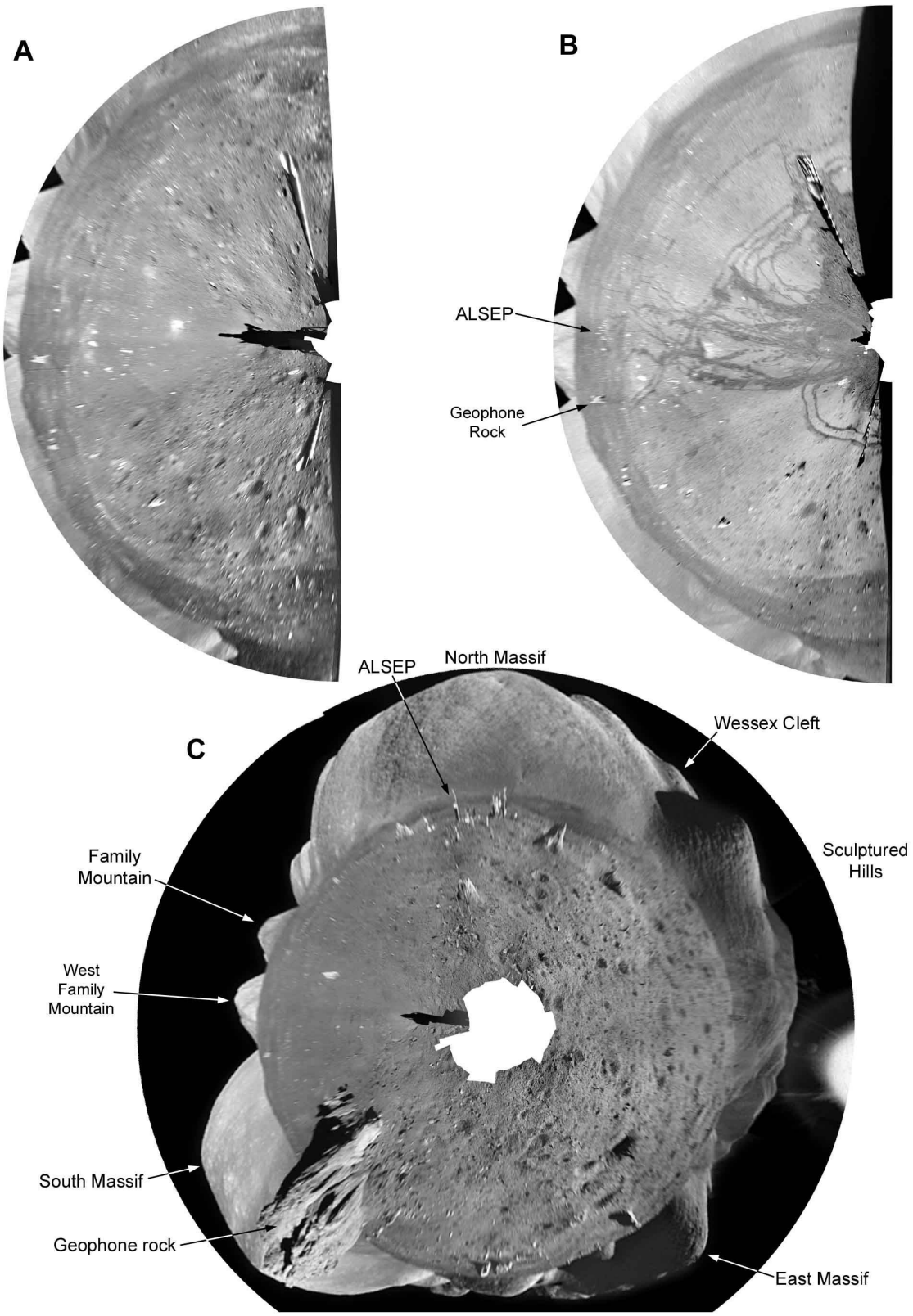


Figure 319. Apollo 17 panoramas projected into circular views. The mountainous horizon has been cropped out in A and B. A: view from LM windows before EVA 1. B: view from LM windows after EVA 3. C: panorama at the ALSEP site, EVA 1.

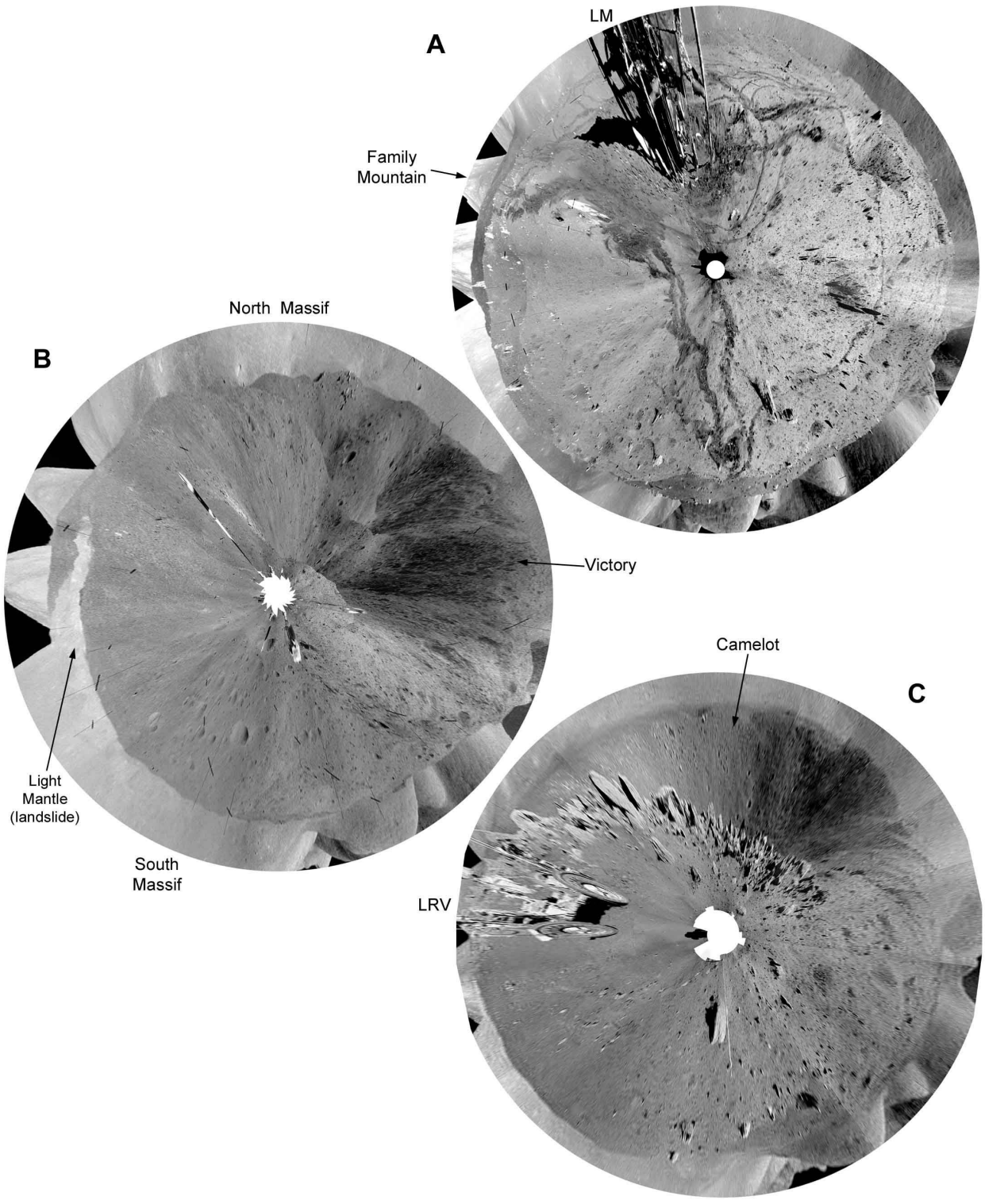


Figure 320. Apollo 17 panoramas projected into circular views. The mountainous horizon has been cropped out. A: panorama south of the LM, EVA 2. B: rover panorama at Victory crater, EVA 2. C: panorama at Station 5, Camelot crater, EVA 2.

The ascent stage target point was 19° 55.8' N, 30° 32.4' E, or 19.93° N, 30.54° E, as stated in the Apollo 17 final flight plan. The intention was to strike South Massif and if possible to view the impact with the rover camera. Initial estimates of the impact location put it at 19° 54' N, 30° 30' E, a position later revised to 19.96° N, 30.50° E (19° 57.6' N, 30° 30' E) (NASA 1972c, 1972d). Figure 272A shows these sites. Also shown are the same points as depicted on an unidentified NASA graphic from the Apollo Lunar Surface Journal (https://www.nasa.gov/wp-content/uploads/static/history/alsj/a17/a17.labeled.TL.jpg). The points on that image are 1 km from the plotted coordinates, though any attempt to define positions on a map using coordinates from another source is only as accurate as the control used for the map and the source.

In 2005 new Hubble Space Telescope images were taken of the Taurus-Littrow Valley (Space Telescope Science Institute, 2005) using the Advanced Camera for Surveys (ACS). They show (but only with hindsight) the bright patch created by the LM landing (Figure 322) and answer a question often asked about the ability of Hubble to show Apollo landing sites. Hubble's resolution at the Moon is far inferior to any orbiting scientific camera.

Samples of the highland massifs gave ages of 3.87 billion years for the Serenitatis basin. The valley floor basalts were about 3.7 billion years old. The landslide was 110 million years old, which may date Tycho crater if the slide was initiated by Tycho secondaries (Wilhelms *et al.,* 1987). The more recent observation that there are several landslides, and that the 'thumb' is older than the main slide, weakens the association with Tycho. Movements on the thrust fault which formed the scarp may be the triggers for these slides (Watters and Schmerr, 2025).

Figure 322 shows the areas imaged from orbit by Apollo 17. As with all other Apollo missions, high resolution photography was obtained along the ground track, including frames showing parts of the Orientale basin illuminated by earthshine. Low resolution views of a broader area were taken after leaving lunar orbit. Some additional time was allowed in lunar orbit to maximize the amount of orbital photography on this last Apollo mission.

At the 55th Brown/Vernadsky Microsymposium just before the 45th LPSC in March 2014, Harrison, Schmitt offered new interpretations of the Apollo 17 site, which he was still studying. The Station 6 and 7 boulders were interpreted as being from different layers. Station 7 samples may be from an Imbrium ejecta layer, and the Station 6 rocks may be stratigraphically lower, possibly from a layer of Serenitatis ejecta overlying the massif. Schmitt said he walked over the Station 7 boulder track without recognizing it, as it was more subdued than the Station 6 track.

Six Apollo 17 samples were stored without opening, some of them kept at -20° C to keep them pristine for future analyses. That new work began in 2020 in a project called Apollo Next Generation Sample Analysis (ANGSA) to help prepare a new generation of researchers for Artemis exploration and sampling (Shearer *et al.,* 2024).

Defense Mapping Agency (DMA), 1975. *Apollo 17 Traverses*. NASA Lunar Photomap 43D1S2(25), edition 1, original scale 1:25,000, March 1975. https://www.lpi.usra.edu/resources/mapcatalog/LPST/43d1s2/150dpi.jpg

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MSC, 1972. *Apollo 17 final lunar surface procedures*, Manned Spacecraft Center, Houston, Texas, 6 November 1972.

Muehlberger, W. R. *et al*., 1973. Preliminary geologic investigation of the Apollo 17 landing site. Apollo 17 Preliminary Science Report, NASA SP-330, pp. 6-1 to 6-91. Washington, D. C.: National Aeronautics and Space Administration.

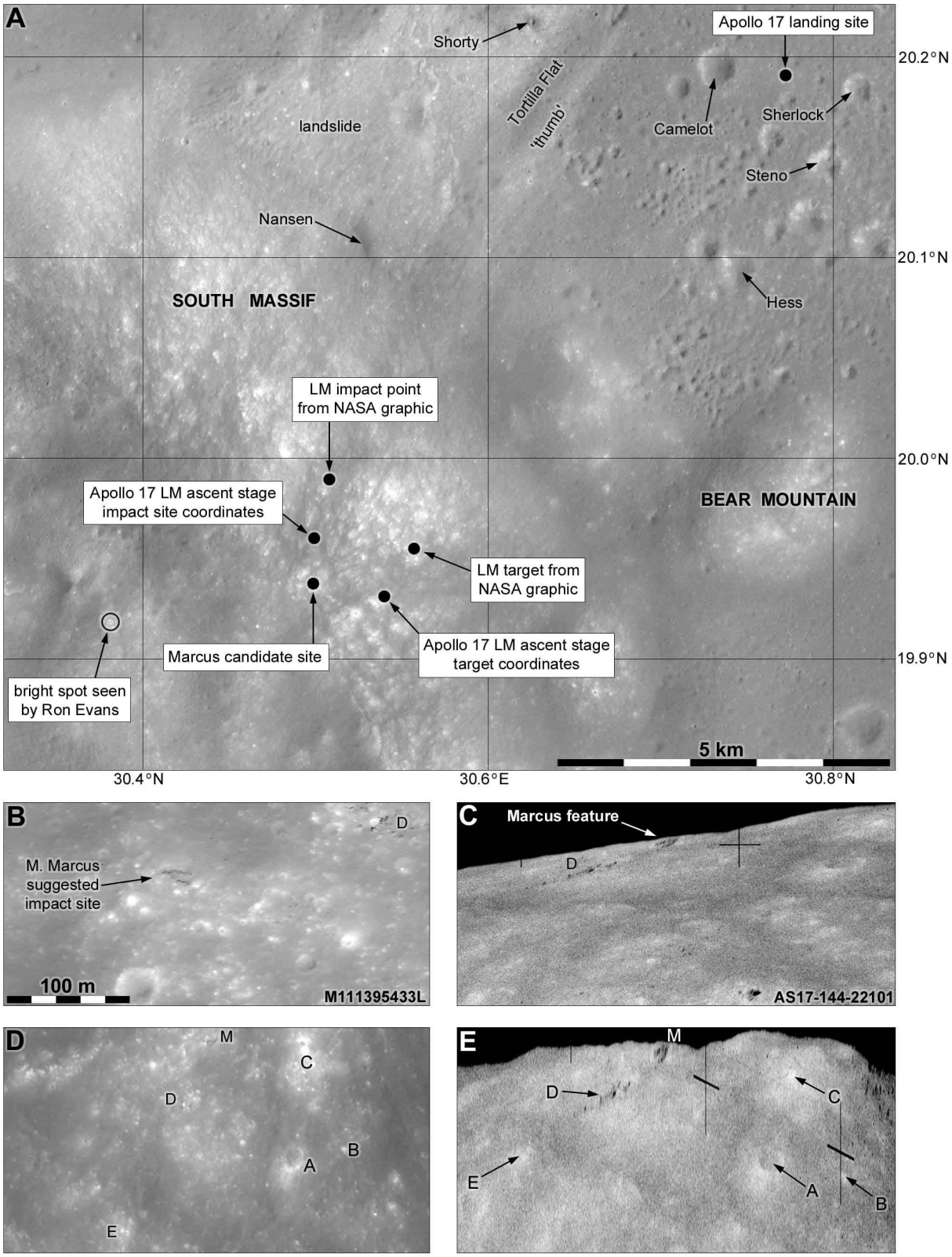

Figure 321: Apollo 17 LM Ascent Stage impact site. A: several suggestions for the locaion. B, C: the site suggested by Marcus in an LRO NAC image and an image taken during EVA 2. D, E: images from B and C compared. D is rotated, E is stretched to facilitate comparison.

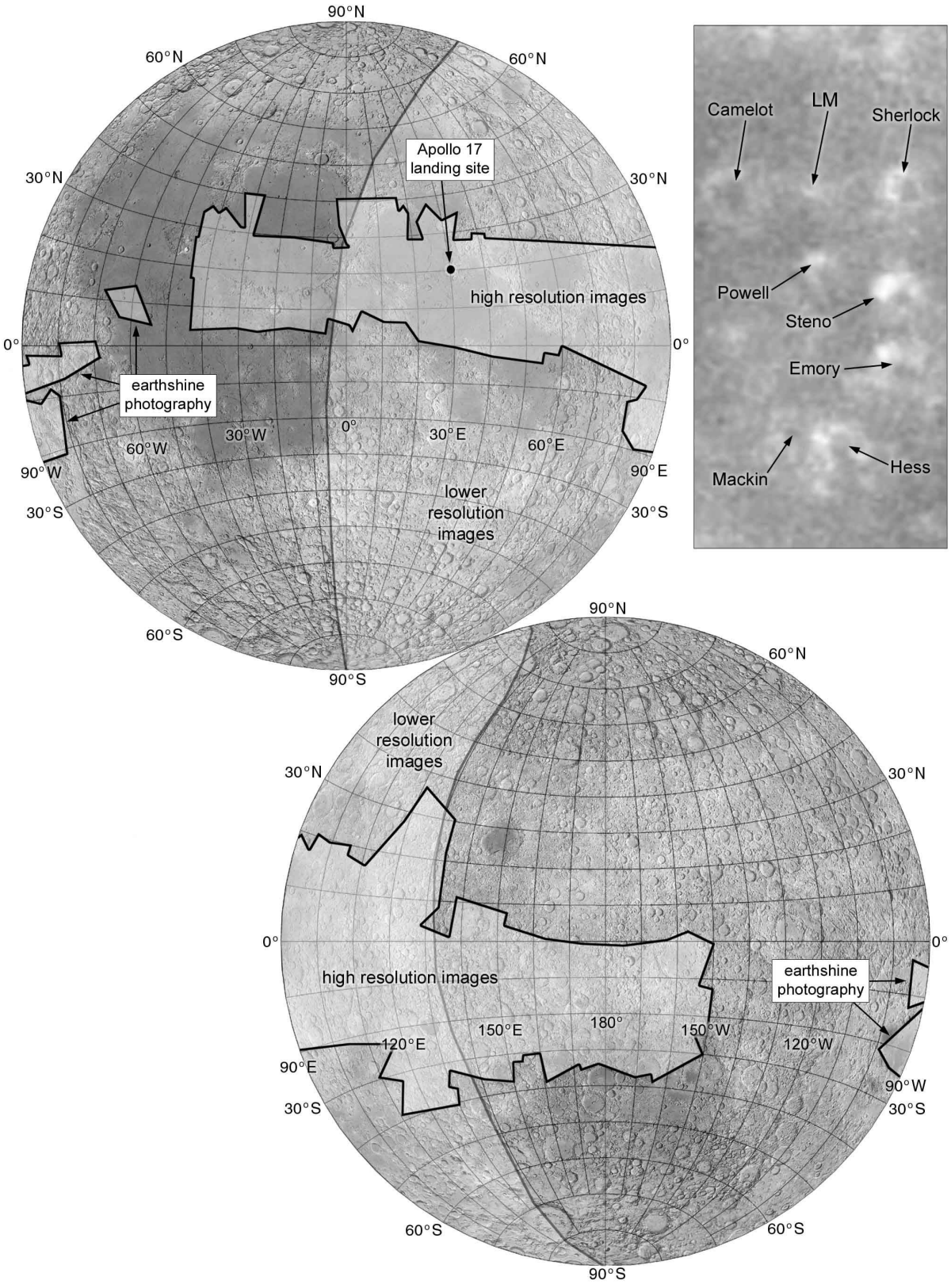

Figure 322: Apollo 17 orbital photographic coverage. Inset: Hubble Space Telescope image of the Apollo 17 landing site (NASA, ESA, J. Garvin).

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NASA, 1972b. *Apollo 17 prelaunch mission operation report*, NASA Office of Manned Space Flight, Washington, D. C., 28 November 1972
NASA, 1972c. *Apollo 17 Post-Launch Mission Operations Report*, No. M-933-72-17, 19 December 1972.
NASA, 1972d. *Mission Director's Summary Report, Apollo 17*. 19 December 1972. Washington, D. C.: National Aeronautics and Space Administration.
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Schmitt, H. H., 2017. Geology and stratigraphy of Shorty crater pyroclastic ash deposits. Presented at the 48th Lunar and Planetary Science Conference, 20-24 March 2017, The Woodlands, Texas. Abstract no. 1072.
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Schmitt, H. H., Eppler, D. B., Petro, N. E. and Head, J. W., 2021. Lessons learned for Artemis from science back room support of the Apollo missions. Presented at the 8th Lunar Surface Science Workshop, Structuring Real-Time Science Support of Artemis Crewed Operations, held online on 24-25 February 2021. Abstract no. 3025.
Shearer, C. K., McCubbin, F. M., Eckley, S. *et al*., 2024. Apollo Next Generation Sample Analysis (ANGSA): an Apollo Participating Scientist Program to Prepare the Lunar Sample Community for Artemis. *Space Science Reviews*, v. 220, 62. https://doi.org/10.1007/s11214-024-01094-x
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Watters, T.R. and Schmerr, N.C., 2025. Paleoseismic activity in the moon's Taurus-Littrow valley inferred from boulder falls and landslides. *Science Advances*, v. 11, no. 31, p. eadu3201. https://www.science.org/doi/10.1126/sciadv.adu3201
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Wolfe, E. W. *et al*., 1981. *The Geologic Investigation of the Taurus-Littrow Valley: Apollo 17 Landing Site*. U. S. Geological Survey Professional Paper 1080. Washington, D. C.: U. S. Geological Survey.

1972: Apollo Orbital Data: Lunar Consortium

The last three Apollo flights carried instruments in the SIM (Scientific Instrument Module) bay of the Service Module to observe the lunar surface during the orbital part of the missions (Table 75). The non-photographic datasets were mapped in a common format by a team called the Lunar Consortium.

Table 75. Apollo SIM bay instruments

Apollo 15, Apollo 16	**Apollo 17**
Panoramic and Mapping Cameras	Panoramic and Mapping Cameras
Laser Altimeter	Laser Altimeter
S-Band Transponder	S-Band Transponder
X-Ray Fluorescence Spectrometer	Infrared Scanning Radiometer
Alpha Particle Spectrometer	Far Ultraviolet Spectrometer
Mass Spectrometer	Lunar Radar Sounder
Bistatic Radar	
Note: the Bistatic Radar and S-Band Transponder were also carried on Apollo 14	

The spectrometers provided surface composition data for broad regions, showing the distribution and abundance of elements such as iron, potassium, thorium and titanium (Figure 323B). The Infrared Scanning Radiometer provided temperature maps of the surface. Radar Sounder data revealed subsurface geological structures. The Bistatic Radar reflected microwaves off the lunar surface, to be received on Earth, providing information on regolith particle size and electrical properties.

The results of these experiments were presented at the Fifth, Sixth and Seventh Lunar Science Conferences in Houston in 1974, 1975 and 1976 and were made available in poster form by the Lunar Science Institute, Houston, Texas. The digital records from which these figures were created were made available by USGS Flagstaff.

Figure 323 shows some of the orbital results. Figure 323A is a sample of topographic relief mapping from metric camera stereoscopic photography, by Sherman Wu and colleagues at the U. S. Geological Survey in Flagstaff, Arizona. The high resolution topography from stereo images was controlled vertically by the low resolution laser altimeter data. Figure 323B presents maps of iron, thorium and titanium created from orbital spectrometer data, and topographic relief from the laser altimeters. In all these maps, white indicates higher values of elevation or element concentration, dark indicates lower values. Data were only collected under the Apollo groundtracks.

Figure 323C is a map of the two geophysical networks established during the Apollo period, including two Soviet Lunokhod sites. These were the Apollo seismic network and the Apollo-Luna laser ranging network with the two Lunokhods. All future network concepts grew out of these foundations. The map projection used here (azimuthal equidistant) emphasizes the very small part of the lunar surface covered by these networks, which is exaggerated in the orthographic maps commonly used for maps like this.

The seismometers observed numerous seismic events (‘moonquakes’) and impacts. Locations of these events could be estimated, and the map shown here is from Khan and Mosegaard (2002). Other maps differ slightly in the number and locations of sources. Figure 324A shows the sources of seismic events as understood in 2002, which were often used to plan future network designs, for instance by placing new instruments antipodal to strong moonquake sources so the signals would pass through the lunar core region. The two sources most often invoked for this were A1 and A33, which are labelled on the map. Shallow moonquake sources were up to about 200 km deep, and the deep

moonquake sources were roughly 700 to 1000 km deep. The map also shows the locations of events thought to be metorite impacts.

Apollo photography greatly extended the coverage of high resolution imaging from the Lunar Orbiters, though this was limited to the orbital ground tracks of the missions. This new material allowed existing maps to be extended to new areas and made at larger scales. The Lunar Map series (illustrated in Figure 325A) was conceived as an update of the LAC charts (Figure 4 in Chronicle part 1), incorporating Apollo images and topographic data from stereoscopic imaging. Some existing LACs were revised and new sheets were produced in limb and farside areas. Only 12 sheets were published, with many more in various stages of completion, before DMA (Defense Mapping Agency, the successor to the Aeronautical Chart and Information Center and the Army Map Service) abandoned lunar cartography in 1978. The U. S. Geological Survey began planetary mapping with Mars and Mercury in the early and mid-1970s and took over lunar mapping later in the decade.

DMA also developed a new series of Lunar Topographic Orthophoto (LTO) maps covered most of the area imaged by Apollo 15, 16 and 17 metric cameras at 1:250,000 scale with contours greatly exceeding in accuracy the pre-Apollo LAC sheets (Figure 325B). Special areas of interest including landing sites and unusual features such as Ina were mapped at larger scales. New placenames were incorporated into these maps, notably Fahrenheit (previously Picard X) and Dorsa Harker (Harker Ridges) in the Luna 24 area. Figure 325 shows details of maps of the Luna 24, Apollo 15 and Apollo 17 sites and a special scientific target, a small breached volcanic cone called Isis at 18.953° N, 27.482° E, south of the Apollo 17 landing site.

Khan, A. and Mosegaard, K., 2002. An inquiry into the lunar interior: A nonlinear inversion of the Apollo lunar seismic data. *Journal of Geophysical Research*, v. 107, no. E6, 10.1029/2001JE001658.

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St. Clair, J. H., Carder, R. W. and Schimerman, L. A., 1979. United States lunar mapping - a basis for and result of Project Apollo. *The Moon and the Planets*, v. 20, no. 2, pp. 127-148. https://doi.org/10.1007/BF00898062

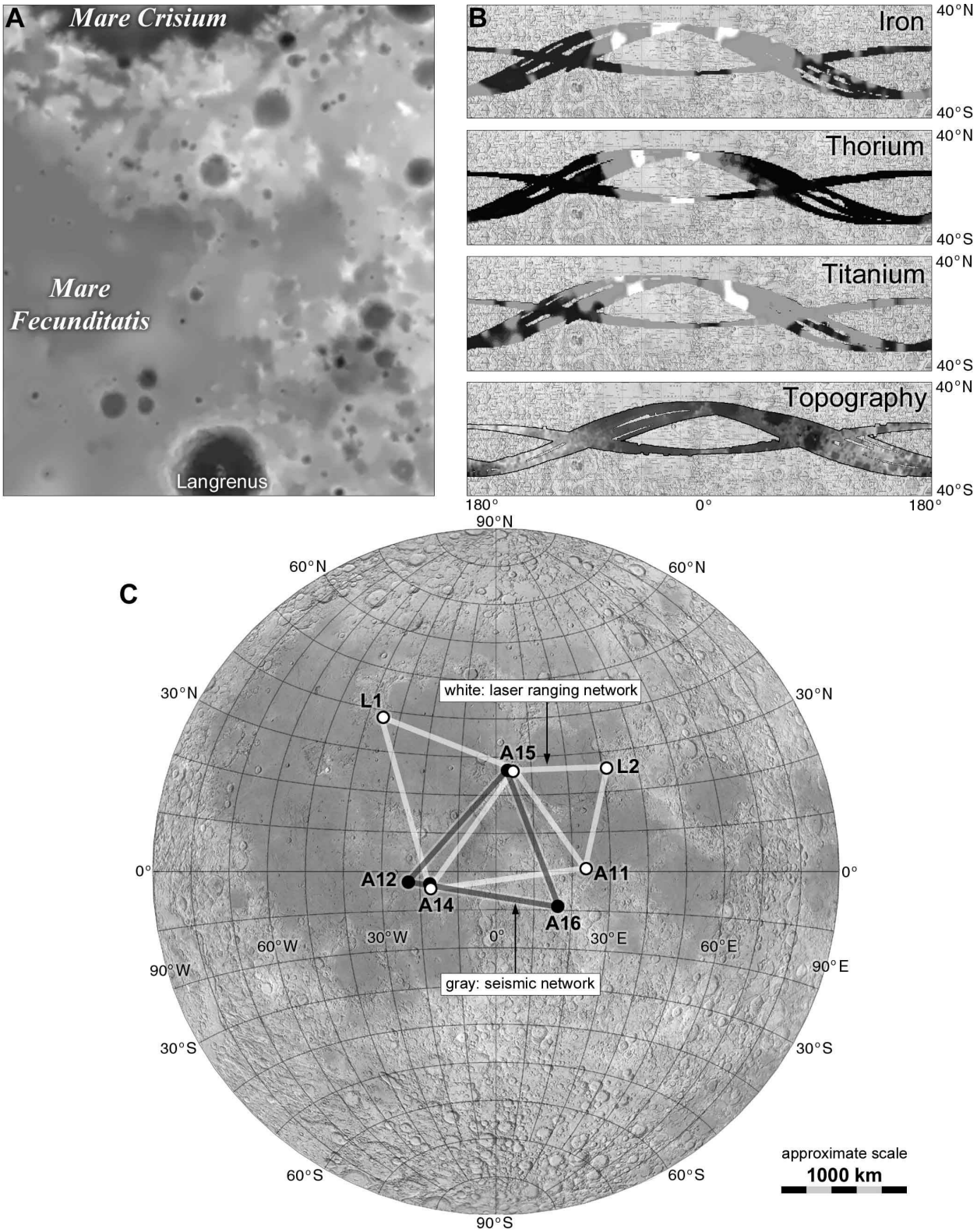

Figure 323: Apollo orbital data and networks. A: Topography from stereoscopic images. B: element abundances. In A and B, darker shades represent lower values of elevation or abundance. C: Apollo laser ranging and seismic networks.

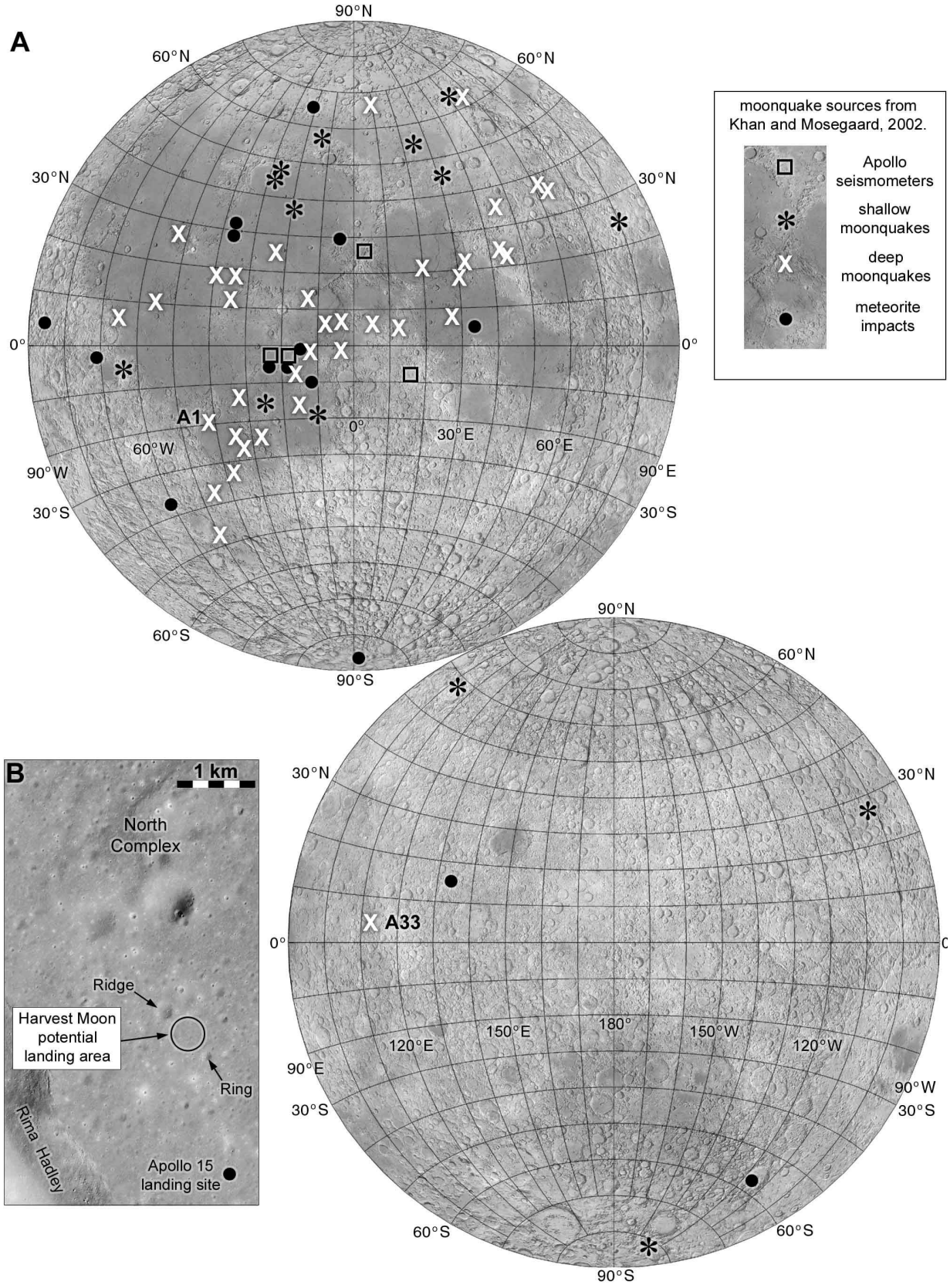

Figure 324. Apollo seismic source locations and Harvest Moon potential landing area.

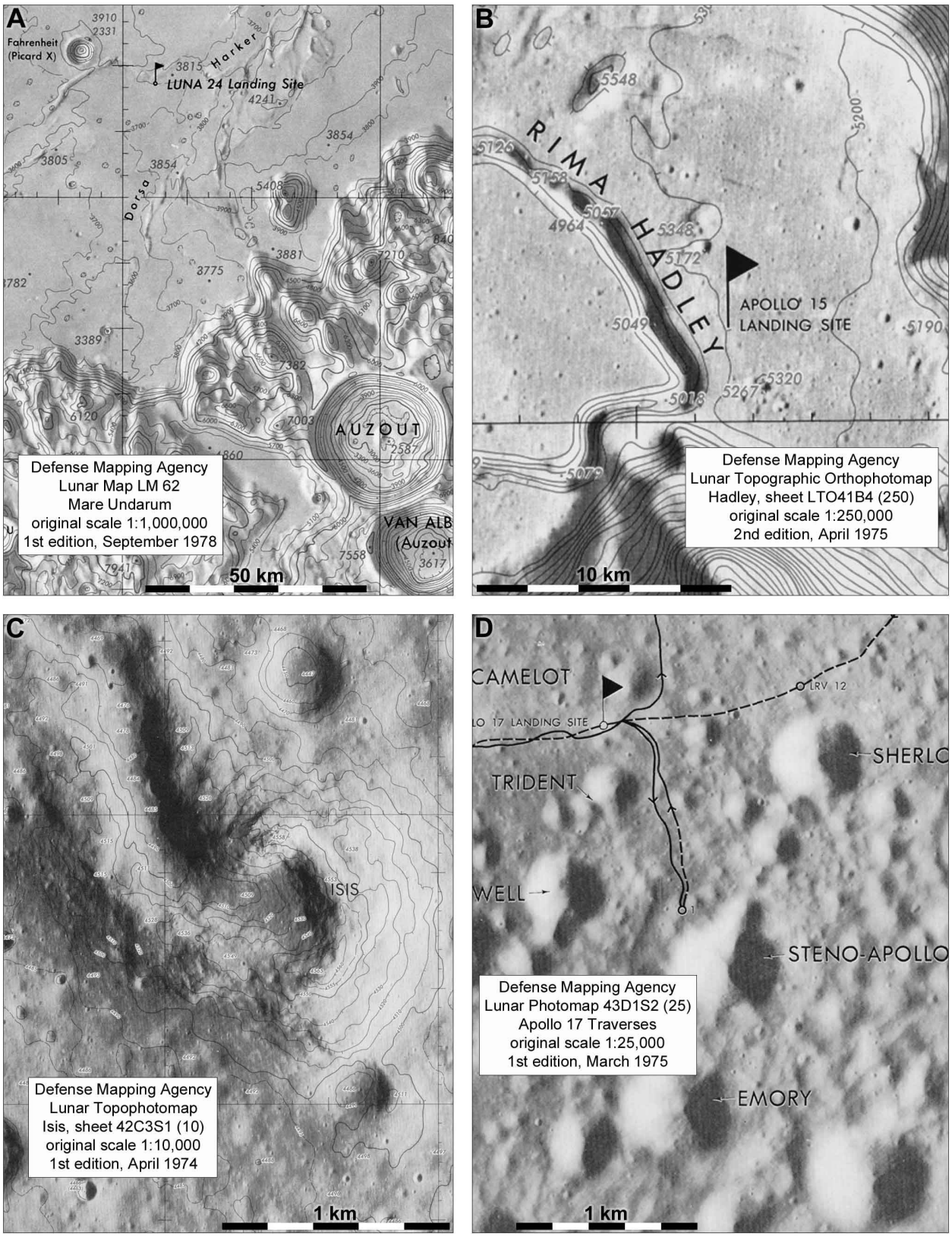

Figure 325. Maps made by the Defense Mapping Agency (DMA) using Apollo data. Only small extracts from each map are shown.

1973: Harvest Moon

The Committee for the Future, a group based in Lakeville, Connecticut, proposed using Apollo hardware from cancelled Apollo missions to fly a mission to the Moon, funded by worldwide public donations and the sale of Apollo and lunar material returned to Earth. The plan was to return to the Apollo 15 landing region with the Apollo 15 crew, who would deploy an ambitious package of experiments (Anonymous, 1972; Robinson, 1973).

The package, First Integrated Experiment for Lunar Development (FIELD) would include a 6 m diameter inflated Mylar dome containing plants, insects and possibly small animals, a long range remote controlled rover (ROGER, Remotely Operated Geophysical Explorer) to determine mineral abundances and locate resources, a laser communication system to support the landing and later to function as a communication relay for terrestrial television, and FLO, First Lunar Observatory, a telescope to be controlled from Earth. The longer term goal was to foster international cooperation and space colonization.

Discussions ended when NASA indicated the remaining Apollo hardware would be used for the Skylab program or cannibalised for other projects. Other obstacles included the unwillingness of NASA and Department of Defense to provide launch, communications, recovery and other resources for this flight, and a controversy involving unauthorised sales of stamps carried to the Moon by this crew, which precluded future flights by them in NASA's view.

The crew would probably have made two walking EVAs, the first to retrieve items of Apollo 15 hardware for sale on Earth, the second to collect samples from the North Complex which was omitted from Apollo 15's EVA 3 (Figure 241 in Chronicle part 5). A landing point half-way between these locations would have been chosen, perhaps near Ridge and Ring craters (Figure 324B) (Doug Van Dorn, personal communications, June 2005).

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8 January 1973: Luna 21 and Lunokhod 2

The 4850 kg Luna 21 spacecraft was launched from Baikonur at 06:56 UT on 8 January 1973 on a Proton booster, placed in a low Earth parking orbit and then sent on its lunar trajectory. It carried Lunokhod 2, the Soviet Union's second lunar rover. The spacecraft experienced power problems which necessitated opening the Lunokhod solar panel in flight to augment power. It was stowed again for the trajectory correction and orbit insertion burns and for landing. Other reports suggested that the rover lid and solar panel opened uncommanded. On 12 January Luna 21 entered a 90 by 100 km lunar orbit inclined 60º to the equator.

After a day in orbit the low point was reduced to 16 km, and on 15 January after 40 orbits the vehicle braked and dropped to just 750 m above the surface. Then the main thrusters slowed the descent, and at 22 m a set of secondary thrusters took over until the spacecraft was only 1.5 meters above the surface, when the thrusters were shut off. Landing time was 23:35 UT on 15 January. The landing site was in Le Monnier crater on the eastern edge of Mare Serenitatis, nearly 200 km north of the Apollo 17 landing site (Figure 326A). The first attempted Lunokhod flight on 19 February 1969 was also targeted for this region.

The lander carried images of Lenin and the Soviet coat-of-arms. Its rover, Lunokhod 2, was 170 cm long, 160 cm wide and 135 cm high with a mass of 840 kg, similar in basic form to Lunokhod 1 but 85 kg heavier, and carried a slogan commemorating the 50th anniversary of the formation of the Soviet Union on 30 December 1922. The lander and rover together weighed 1814 kg, and the lander was equipped with two pairs of ramps so the rover could depart from it in either of two directions. The rover had eight wheels, each with its own suspension, drive system and brake. A ninth free-spinning wheel served as an odometer, leaving a narrow track between the wider tracks of the main mesh wheels. The rover could be driven at two speeds, roughly 1000 and 2000 m per hour.

Four panoramic cameras were mounted on the rover. One on each side gave panoramic images in an arc facing forwards, vertically downwards and backwards, and another on each side which gave oblique panoramas extending from the front of the rover to the side and then to the rear. Depending on the rover tilt, these side-looking panoramas would show anything from a small segment of the horizon at each end to an entire horizon panorama. Lunokhod 2 had two forward-facing TV cameras about 1 m above the ground to detect hazards like rocks or craters and an additional TV camera mounted about 75 cm higher to make navigation easier for its terrestrial controllers. The cameras transmitted images at intervals as short as 3 seconds which were used by the drivers in Russia to plan and execute the drive in real time. A solar panel inside a circular lid charged the batteries when the lid was open during the lunar day. At night it was closed to cover the pressurized interior which was kept warm by a polonium heat source. The rover's scientific instruments were a soil mechanics penetrometer, a solar X-ray telescope, an X-ray spectrometer (RIFMA-M) to measure regolith composition, an astrophotometer to measure the visible and UV light levels of the sky, a magnetometer deployed in front of the rover on the end of a 2.5 m boom, a radiometer, a photodetector (Rubin-1) for laser detection experiments, and a French-supplied laser corner-reflector. RIFMA-M was mounted in front of the rover between the front wheels and slightly higher than the wheel axles.

After landing, Lunokhod 2 surveyed its surroundings. This was the most visually dramatic and interesting of all Soviet landing sites, and the rover explored a landscape of craters, mountains and valleys over five lunar days and 39 km of travel. The rover paused for several days around each lunar noon when lack of shadows hampered visibility and made driving difficult, allowing the solar panels to recharge its batteries. It typically began work about 2 days after sunrise and stopped for the night 2 days before sunset.

On June 4 controllers announced that the mission was finished, having failed in mid-May. Details of the traverse follow this summary. Lunokhod 2 was left parked in a position which allowed its laser retroreflector to be used, and it is still functioning today though its signal is weaker than expected, probably because it is not pointed accurately towards Earth (Gao *et al*., 2024a, 2024b). LRO images appear to show the rover pointed well away from Earth but their interpretation is difficult. The final resting place of the rover was 25.832º N, 30.922º E (Wagner *et al*., 2017) or 25.836º E, 30.924º E (Karachevtseva *et al.*, 2017). The rover had driven 39.16 km according to mapping using LRO images, about 2 km more than estimated at the time.

Lunokhod 2 returned 86 panoramic images and over 80,000 TV pictures. Soil mechanics observations, laser ranging measurements and magnetometer readings were conducted throughout the drive. Instruments detected Solar X-rays and monitored the light levels of the daytime sky at visible and ultraviolet wavelengths. The visible light levels during daytime were unexpectedly high, enough to be an impediment to lunar daytime astronomy (Severny *et al.*, 1975), but whether this counter-intuitive result is a true observation or the result of an instrument problem is unclear. The daytime operations of the ultraviolet telescopes on Apollo 16 and Chang'e 3 do not appear to have been affected by unusual sky brightness, but the ultraviolet brightness recorded by Lunokhod 2 was not as high as the visible signal.

Unlike Lunokhod 1 and previous landers, Lunokhod 2's mission was not documented in a large official publication. Contemporary accounts include a geological study by Basilevsky *et al.* (1977), magnetometer results by Dolginov *et al*. (1977) and a summary of results by Florensky *et al*. (1978). Another summary is provided by Chaikin (2004). Karachevtseva *et al.* (2017) give an updated account using LRO images of the tracks and new processing of panoramas. Gromov *et al.* (2003) provided additional details of the rover design.

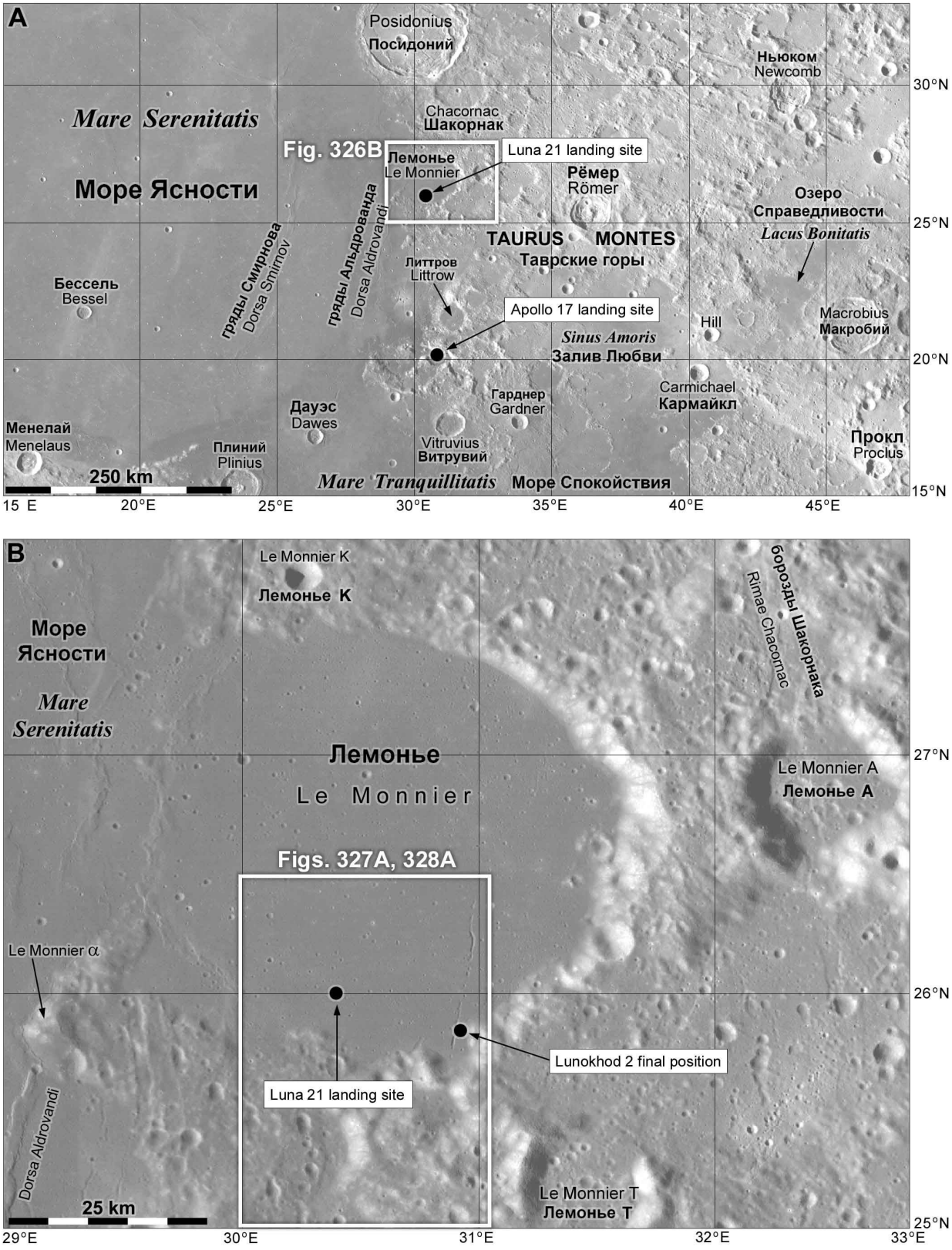


Figure 326: Luna 21 landing area. A: the landing region, also showing the Apollo 17 landing site. B: Le Monnier crater and surroundings. The images are LRO wide angle mosaics.

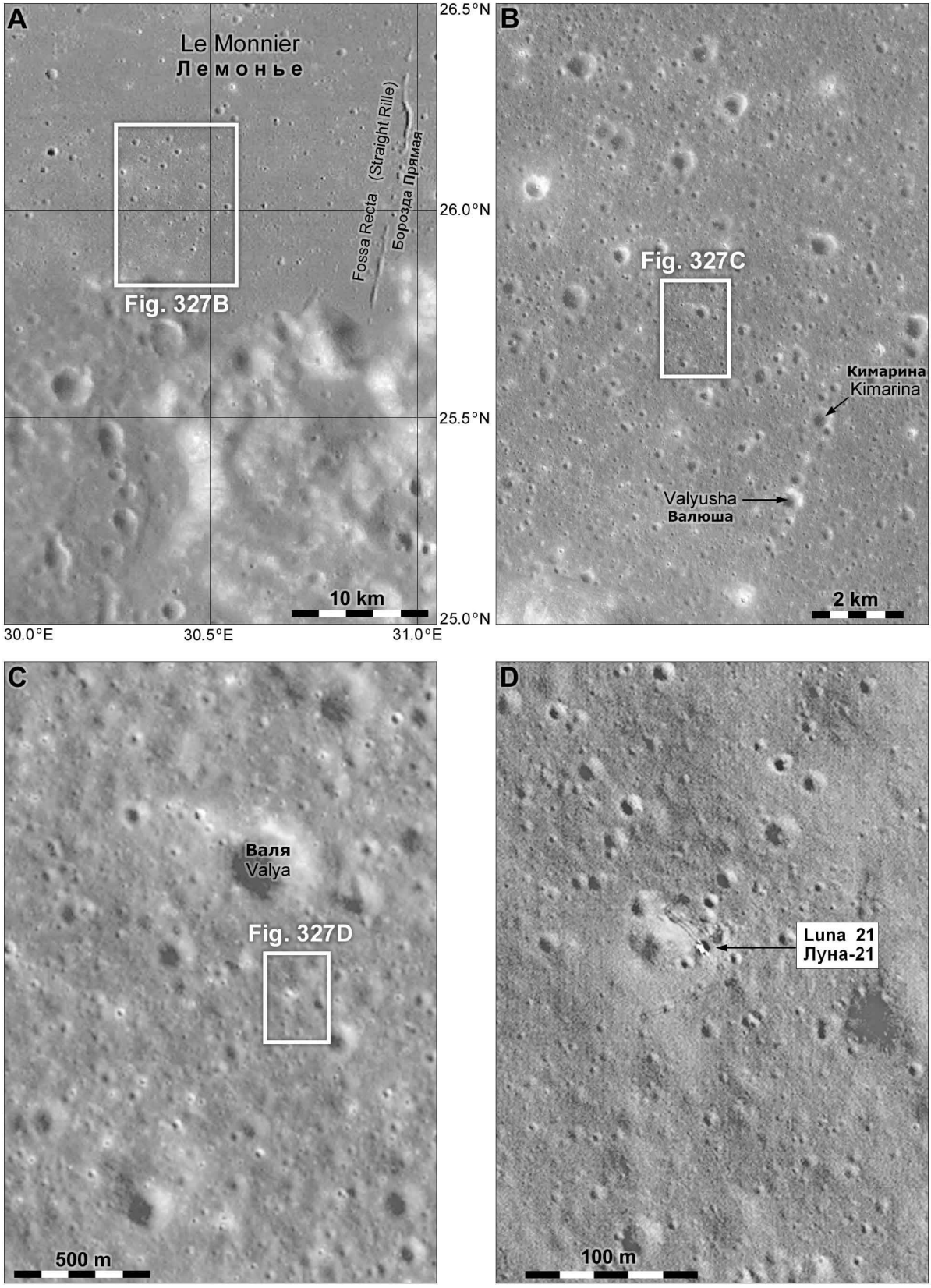


Figure 327. The Luna 21 landing site. C and D are parts of LROC image M122007650L.

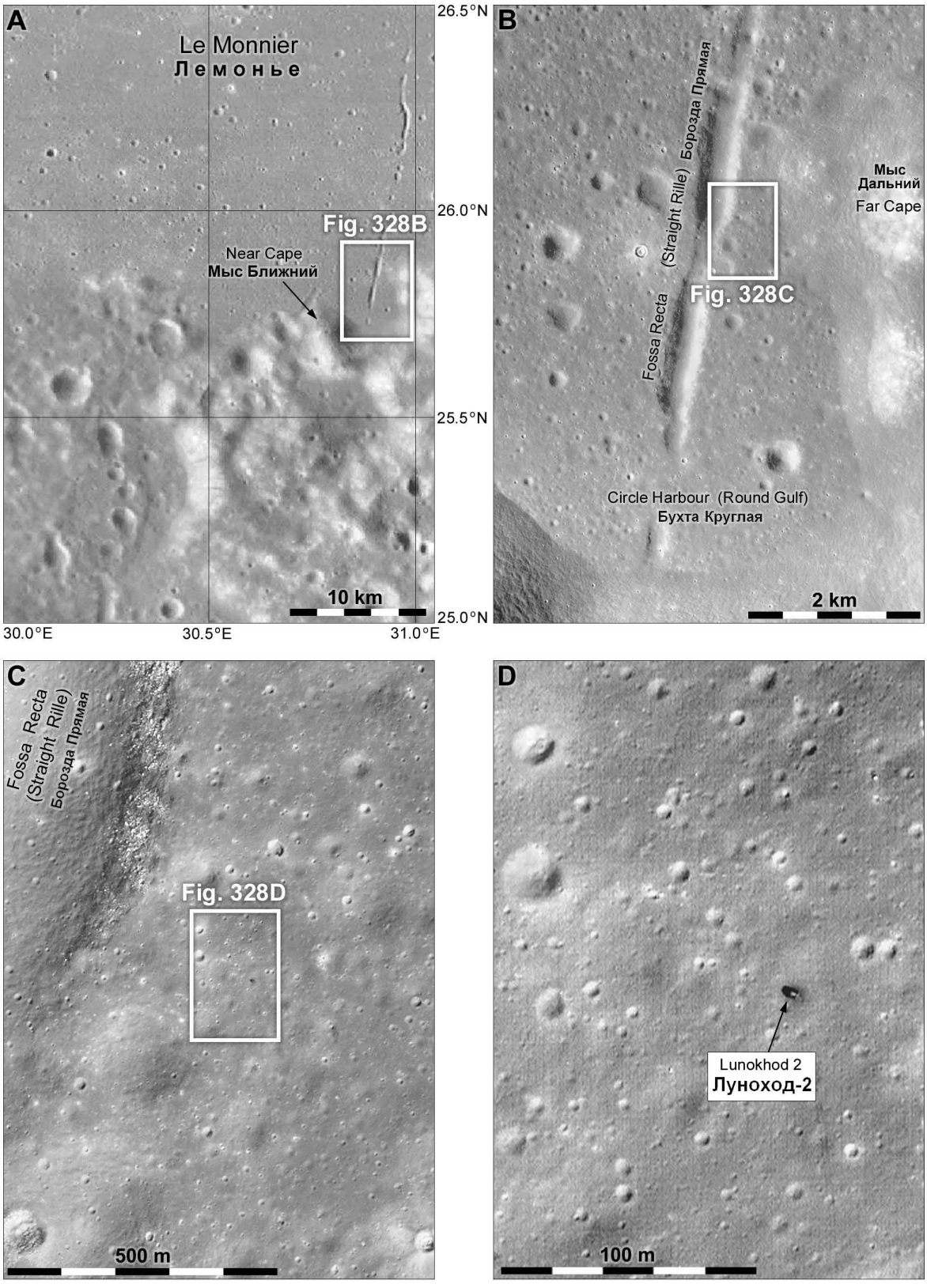


Figure 328. The final position of Lunokhod 2. C and D are parts of LROC image M175070494R.

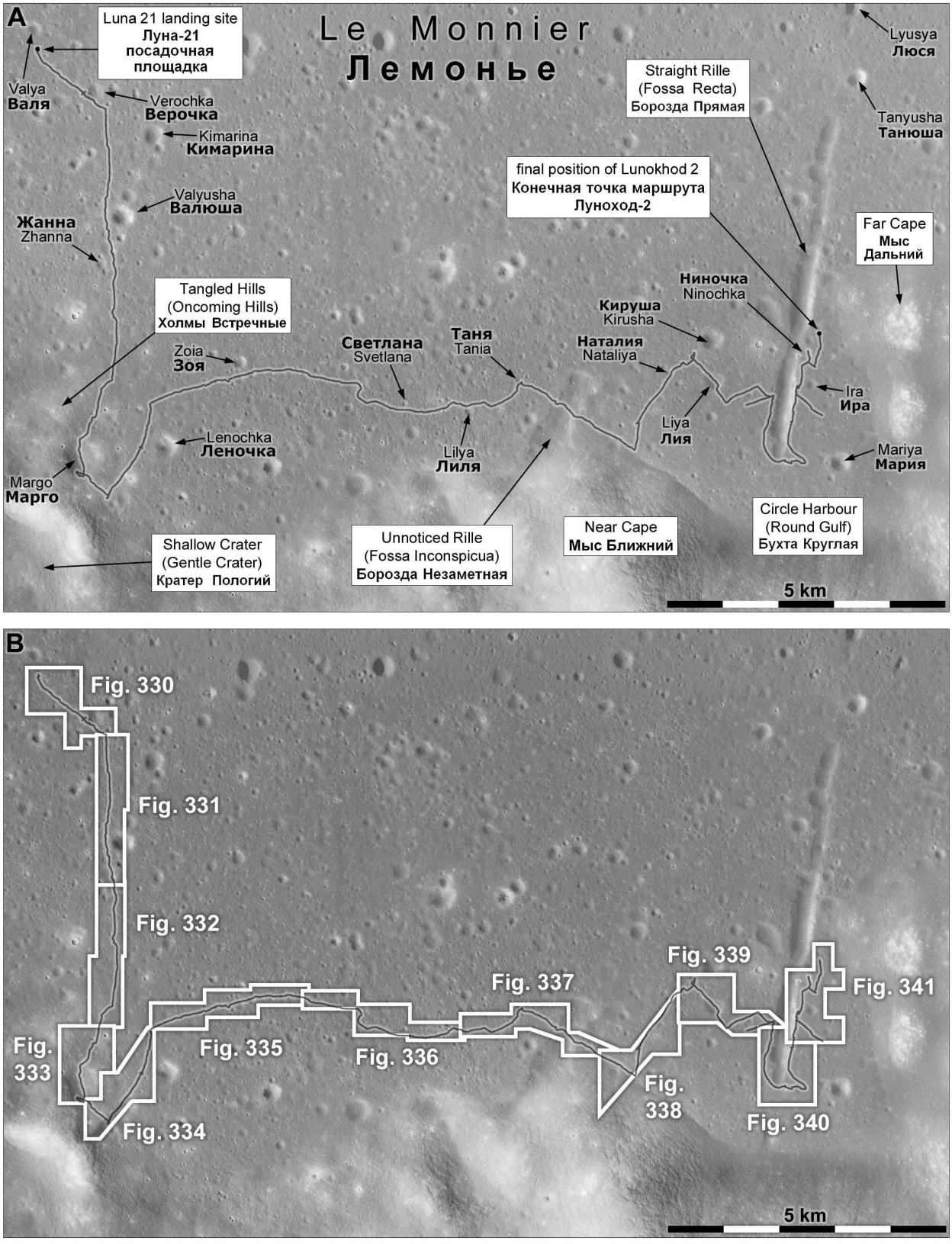


Figure 329. The Lunokhod 2 traverse area. A: Informal placenames. B: index to the route maps in Figures 280-291. The base is a mosaic of LROC NAC images.

The locations of the Luna 21 and Apollo 17 landing sites are shown in Figure 326A. Luna 21 landed about five km north of the hills forming the southern rim of Le Monnier, an old crater partly flooded by lavas from Mare Serenitatis. The low southern rim of Le Monnier was just visible from the landing site (Figure 346). The high eastern rim of the crater near 27° N, 32° E and hills near Le Monnier Alpha to the west were also prominent on the horizon.

Figure 326B is a mosaic of LRO wide-angle images showing the landing area and the outline of Figures 327A and 328A. There are many features of geological interest in this region including a long north-trending straight rille, probably indicating a deep fracture, east of the landing site. Figures 327 and 328 locate the lander and rover.

Figure 329A is an enlargement of Figure 326B showing the Lunokhod 2 route. Several features of the landscape were given informal names after the mission, the only such names given at the time to features at any Soviet landing site. Tangled Hills were also called Oncoming Hills by Abdrakhimov and Shashkina (2008) and Encounter Hills by Karachevtseva *et al.* (2017). Published sources include alternative translations of some names: Unnoticed Rille and Straight Rille were also called Fossa Inconspicua and Fossa Recta respectively, in latinized forms similar to official lunar names. Round Gulf was also translated as Circle Harbour, and Shallow Crater as Gentle Crater. A map made at MIIGAiK in 2016 (Karachevtseva and Rodionova, 2016) assigns the names of women to craters in the vicinity of the rover traverse. The names were submitted to the IAU but they have not yet been made official.

Figure 329B serves as an index to the detailed traverse maps presented in Figures 330-341. The tracks were mapped directly from LRO NAC images. Locations of experiments and overnight parking areas are taken primarily from a contemporary map drawn to record the results of this highly successful rover mission. The map has not been published independently, but the western section was reproduced by Vernov (1978, p. 428). That illustration and a reduced version of the full map were kindly provided by Jeanna Rodionova of Sternberg State Astronomical Institute, Moscow. Dates along the route in these figures are taken from the source map, but locations are estimated to match the older map and may not be precisely positioned.

The black line in Figures 330-341 shows the path of Lunokhod 2 with the locations of various observations. An X-Ray Fluorescence Spectrometer measured the regolith composition at locations marked **X**. **P** indicates the locations of panoramic photography, though all panoramas may not be shown. **L** indicates the locations of laser reflector experiments. The laser retroreflector was supplied by France. **S** marks places where the daytime sky brightness was measured. Enlarged details of some sites of interest are given in Figures 342 and 343.

Several small rocks partly blocked the route off the southeast-facing ramp so the rover was driven out to the northwest (Figure 342A) across a shallow crater, leaving the lander at 01:14 UT on 16 January. It rested 30 m from the descent stage until 18 January to recharge its batteries and then drove clockwise around the lander to photograph it and the rim of LeMonnier crater in the background. This area was misrepresented by Stooke (2007) because of a misunderstanding regarding some panoramic image orientations. Comparisons of several Lunokhod 1 panorama sections and detailed plans of sites (Figures 192 and 193 in Chronicle part 4) showed that in some cases the panoramas were printed reversed left to right, and Stooke mistakenly extended that observation to these Lunokhod 2 panoramas. As a result his map of the lander and identifications of distant features were wrong. The record is put right here (Figures 342A, 346).

During the drive near the lander two marks made as the rover turned, a complete circle of tracks and a partial circle, made on 18 January, were represented later as a number 8 to commemorate International Women's Day on 8 March, which was a holiday in the Soviet Union and is in Russia today (Figure 342A). Lunokhod 1 also made a figure 8 for the same reason (Figure 188 in Chronicle Part 4). The rover apparently passed too close to the lander for comfort during its maneuvers, about 4 m away, prompting the drivers to be more cautious. While parked just south of the lander on 18 January the rover used RIFMA-M to measure surface composition. Then Lunokhod 2 was driven about 1200 m further to the southeast on 19 January (Figure 330), towards the hills visible on the southern rim of Le Monnier. It parked to sit out the first lunar night on the rim of Virochka crater after having driven a total of 1260 m. Pictures were returned on 20 and 21 January and the sun set on 23 January.

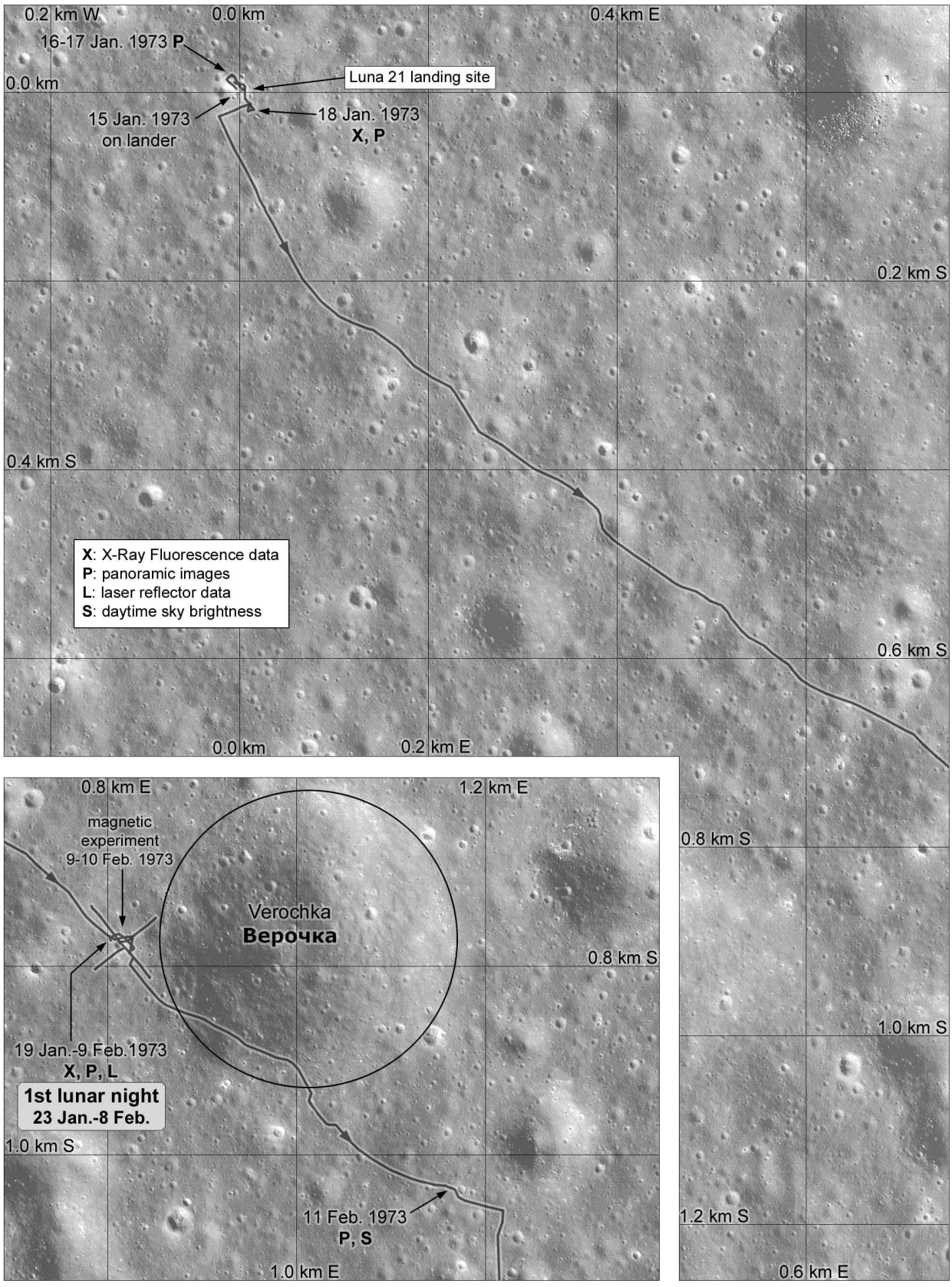


Figure 330. Lunokhod 2 route map, part 1.

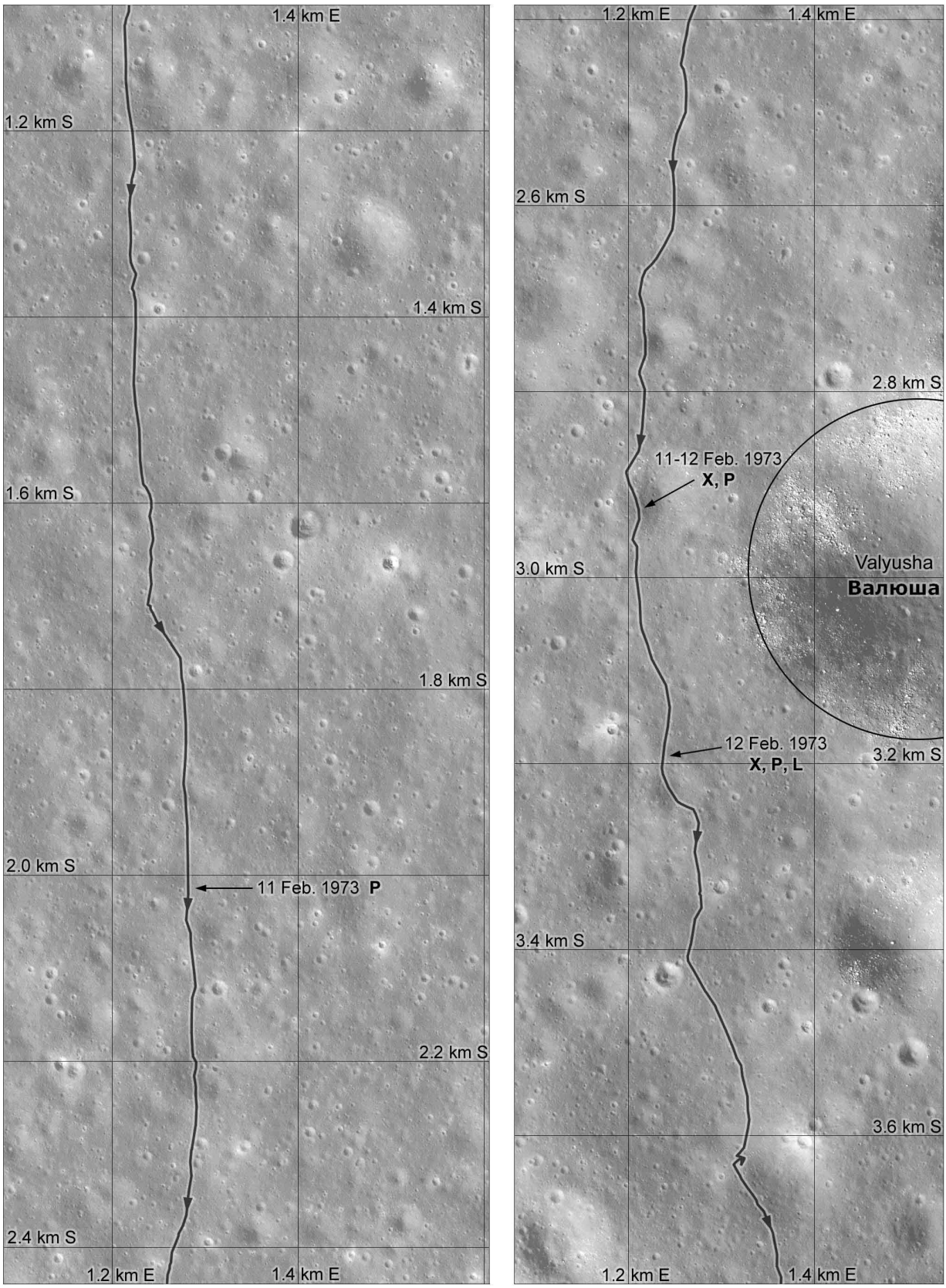


Figure 331. Lunokhod 2 route map, part 2.

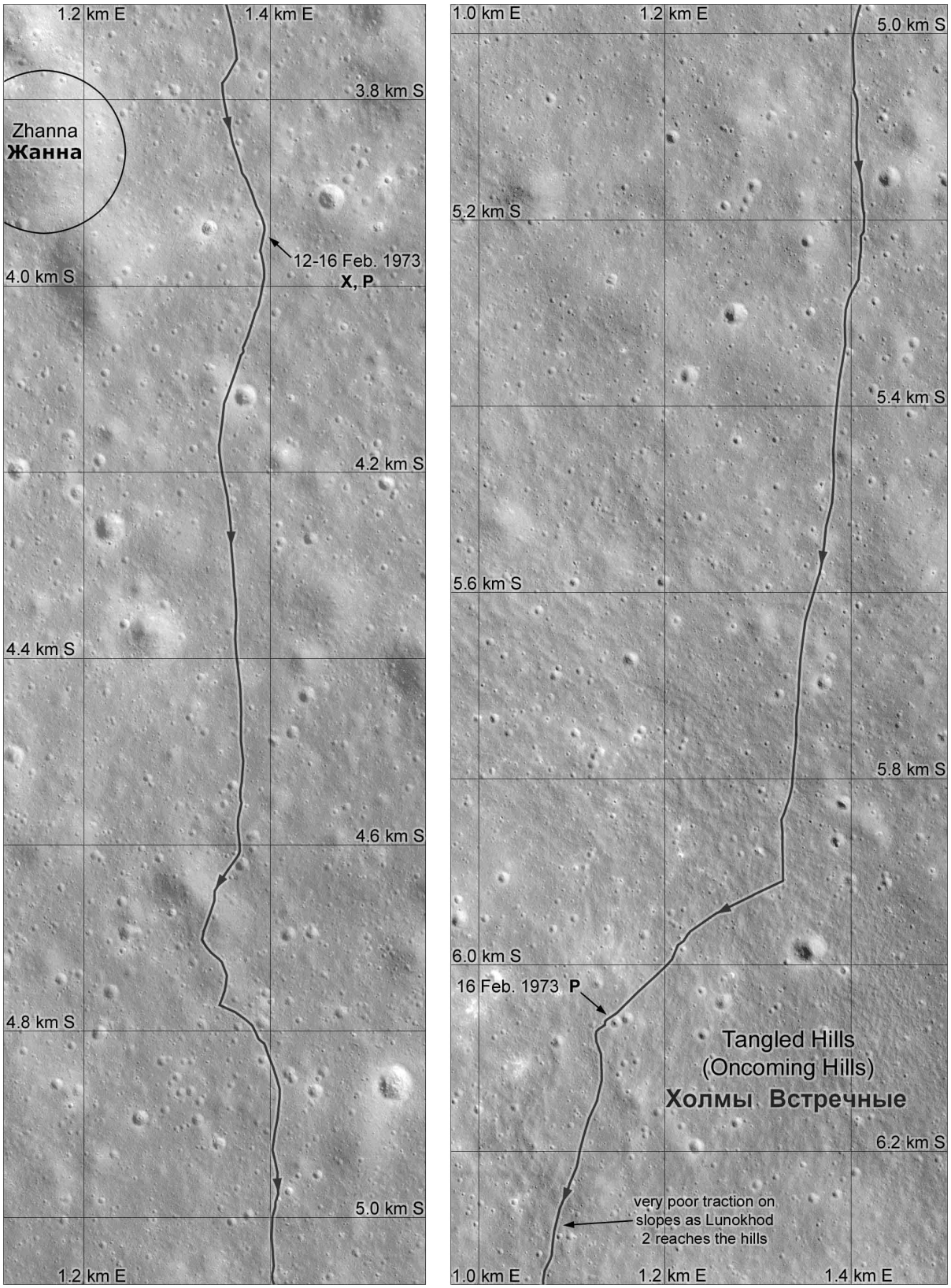


Figure 332. Lunokhod 2 route map, part 3.

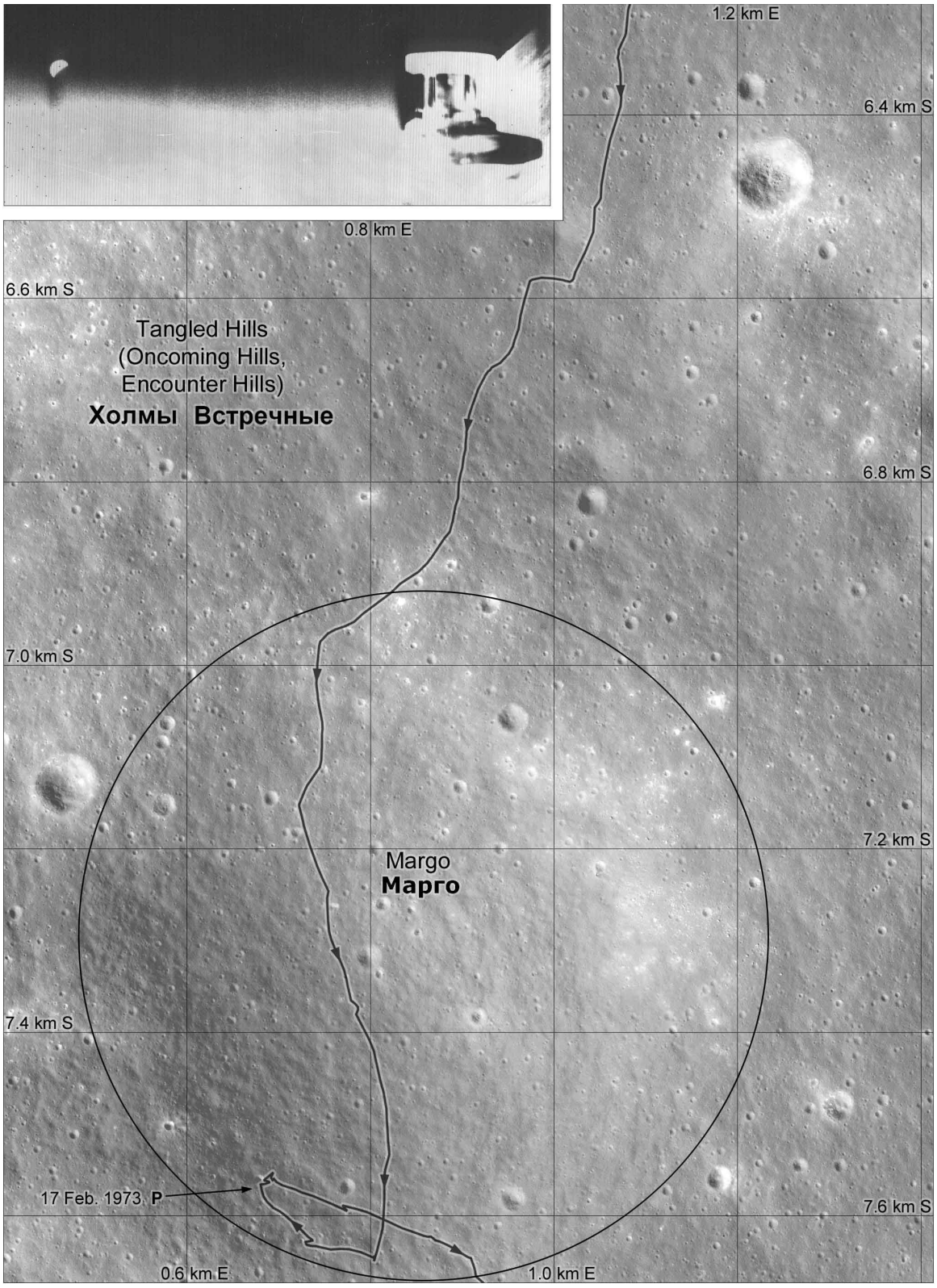


Figure 333. Lunokhod 2 route map, part 4. The inset at top shows Earth viewed above the local hills (right side), probably taken in Margo crater, courtesy of the Lavochkin website (misattributed to Luna 16). (https://www.laspace.ru/upload/iblock/b2b/ityz3vlowmnfhzfr36fnzs20y9k7izr7.jpg)

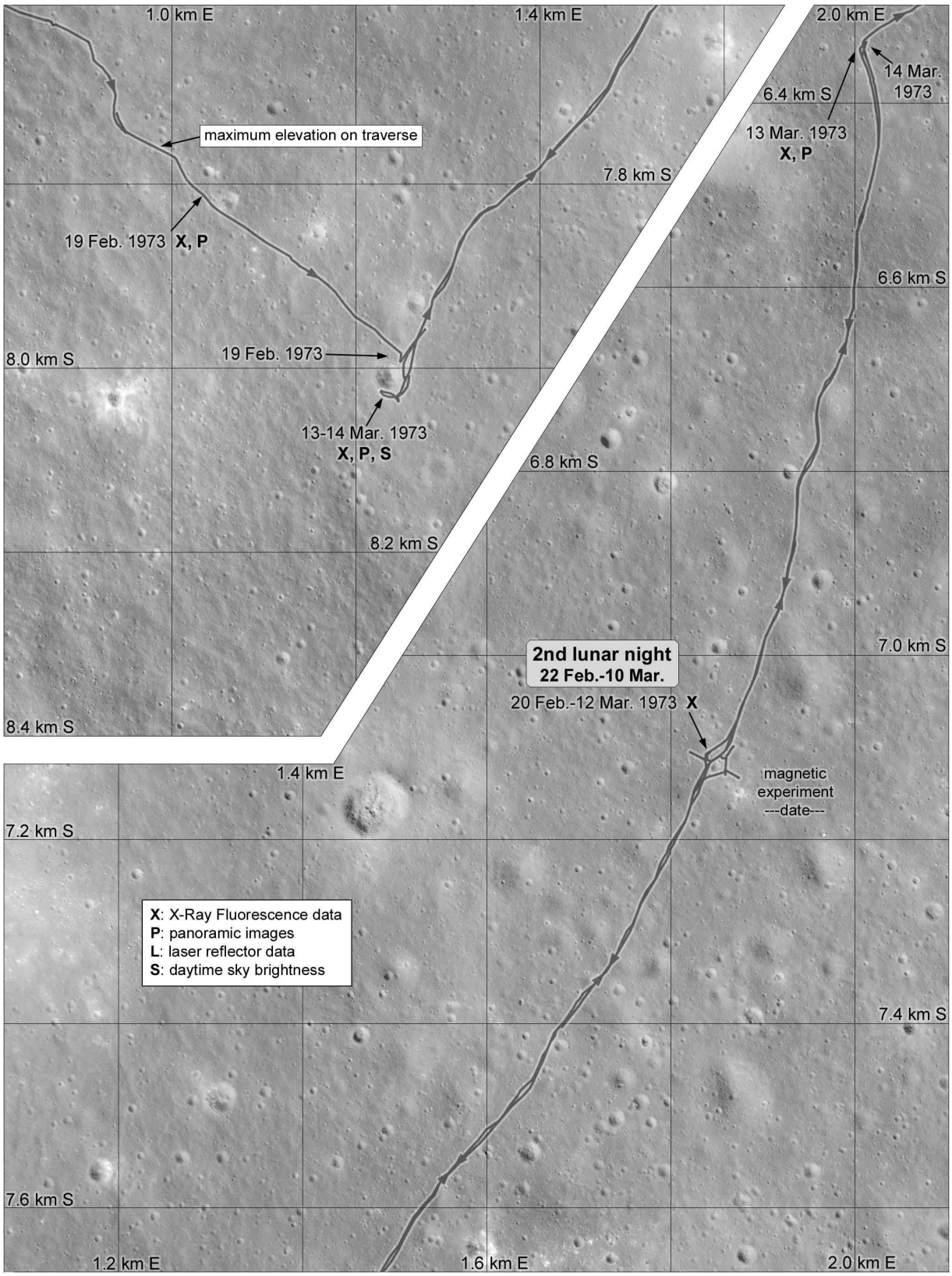


Figure 334. Lunokhod 2 route map, part 5. The triple traverse.

Lunokhod 2 resumed work on 9 February, a day after sunrise, measuring the surface composition and driving in a cross-shaped path around a c. 12 m diameter crater on the rim of Virochka (Figure 342B). This was for a magnetic experiment, measuring the local magnetic field around the crater to see if its formation disrupted the regional magnetic field. Each arm of the cross was driven in both directions to allow researchers to separate the local field from that of the rover itself. The Lunokhod-induced magnetic effects were reversed by rotating the vehicle 180° but the lunar magnetism was unchanged. The rover had to maneuvre carefully to avoid being trapped in the small crater on 10 February. At one point as it approached the crater rim on its north side it failed to stop as commanded (Zak, 2018), rolled over the rim and into the crater, and stopped only when commanded for a third time. Its wheels sank into the loose crater rim regolith up to their axles (Figure 345B). Eventually it was extricated from the crater and completed the magnetometer experiment, but problems continued throughout the mission (Zak, 2018). Electrical components had failed during testing before launch and been replaced, but tests of the new components stressed the rover and shortened the lifetime of the communication system. The failure to stop was traced to a faulty radio component, so it was replaced with a backup. The rover resumed its long traverse on 11 February, turning south towards the distant hills. From 12 to 16 February the rover parked near a large fresh boulder east of the crater Zhanna as the high sun made visibility for driving difficult (Figure 332).

The rover then drove rapidly south to the nearby low hills (Tangled Hills, Oncoming Hills, Encounter Hills in various sources), reaching them later on 16 February. A crater later named Margo appeared ahead, just north of Shallow Crater (Gentle Crater), and Lunokhod 2 entered it on 17 February (Figure 333). The wheels slipped more on these slopes than in the plains, and the southward path was blocked by the steeper slope at the southern wall of Margo. The rover drove 100 m west but the slope was no better, so on 19 February it turned east and ascended the slope diagonally, leaving the crater in a southeasterly direction. This area on the rim of Margo was the highest elevation reached by the rover. Here it took new panoramic images and collected X-ray data on the highland terrain. It drove southeast again for another 300 m and stopped briefly on the north rim of a 25 m crater (Figures 334, 342C). On 20 February it turned northeast and drove from the hills back into the plains for about 1000 m before parking adjacent to another small crater for the second lunar night (Figures 334, 342D). The Sun set on 22 February. Lunokhod 2 had driven 9086 m during the second lunar day, nearly as much as Lunokhod 1 had managed in total.

Ulivi and Harland (2004) reported that Lunokhod 2 climbed a low hill on the second lunar day and took images of the surroundings, viewing Earth as a crescent above the hills. From Le Monnier, Earth would always be seen to the southwest and quite high in the sky. This suggests that the Earth image was taken when the rover was tilted while on a slope, giving it a better view of Earth. If Earth was seen as a crescent the geometry requires that the observation was in the lunar afternoon, and taken together these constraints suggest this event occurred in Margo crater (Figure 333 inset, from the Lavochkin website:
https://www.laspace.ru/upload/iblock/b2b/ityz3vlowmnfhzfr36fnzs20y9k7izr7.jpg).

Lunokhod 2 resumed work on 12 March, two days after sunrise. It conducted another magnetic experiment around the small crater, like that done on 9 February, making a cross shape of tracks around the crater (Figure 342D). It drove about 800 m northeast on 13 March and stopped to take images and soil composition data (Figure 334). Then, as a test of navigation and driving ability the rover was driven rapidly southwest along its tracks for about 2 km, stopping late on 13 March at the foot of the hills on the southern rim of a 25 m crater it had seen on 19 February. Composition and sky brightness measurements were made here. On 14 March it was driven northeast along its tracks again, back to the end point of the drive of the previous day. This repeated traverse ('triple traverse') was used to gather magnetometer data across the mare/highland boundary (Dolginov *et al.*, 1976). Magnetometer measurements along the rest of the traverse were presented by Dolginov *et al.* (1977).

The long drive to the east began on 15 March (Figures 335-339) with a goal of reaching the mountains and the long fracture Fossa Recta in the mare surface to the east as rapidly as possible, given the expected short lifetime of the communications system. The radio system was still causing trouble and again a backup channel had to be used (Zak, 2018). As they drove, periodic stops were made to take panoramic images and soil measurements, though the number of panoramas had to be reduced. Soil mechanics observations and magnetometer readings were made throughout the route, the magnetometer showing varying field directions as Lunokhod passed craters. The rover passed Zoia on 15 March (Figure 335), made an S-shaped maneuvre through complicated terrain on 17 March and then passed Svetlana crater (Figure 336). On 18 March it passed Lilya and entered Tania, but had to back out and bypass that crater (Figure 337).

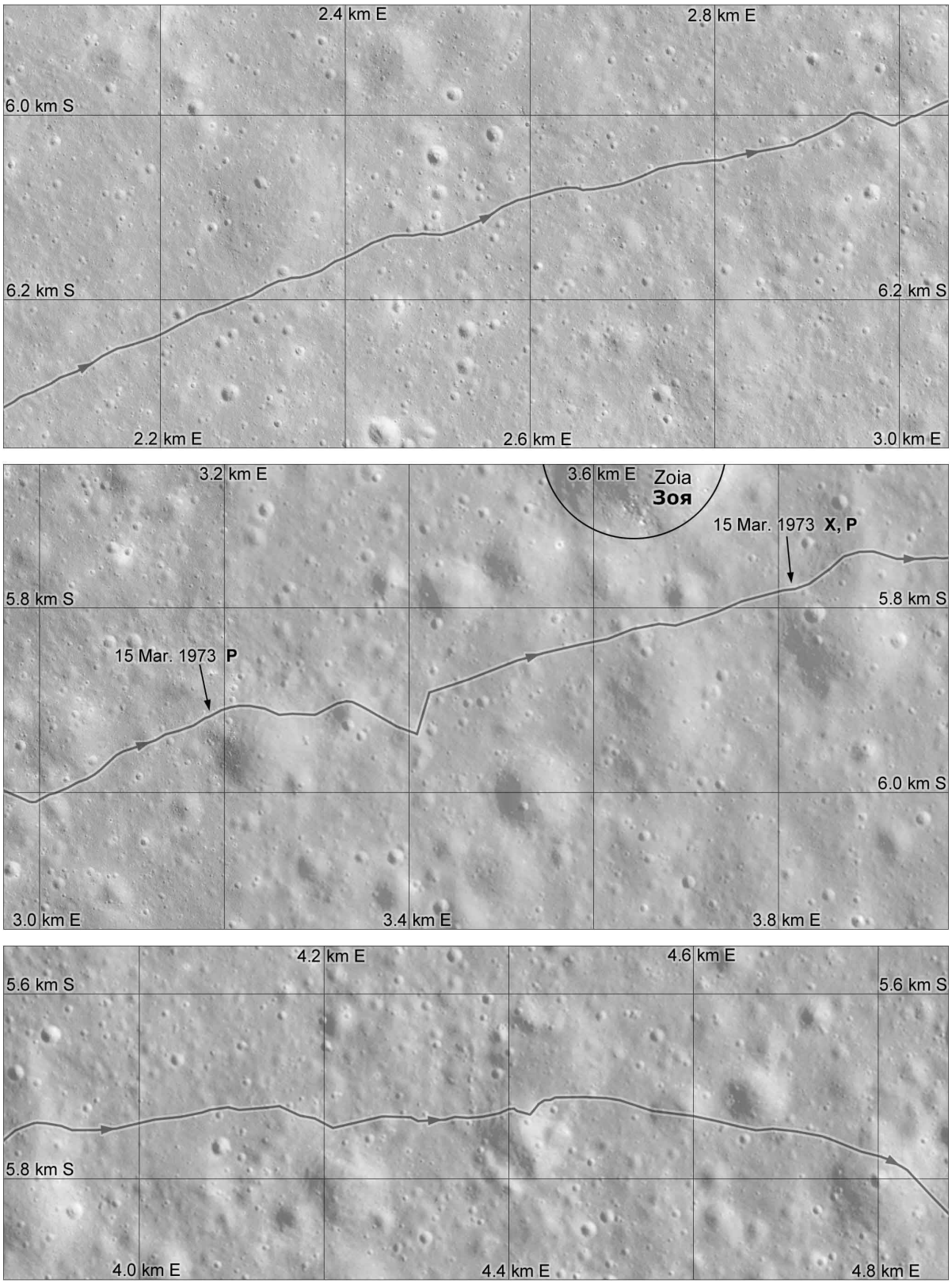


Figure 335. Lunokhod 2 route map, part 6.

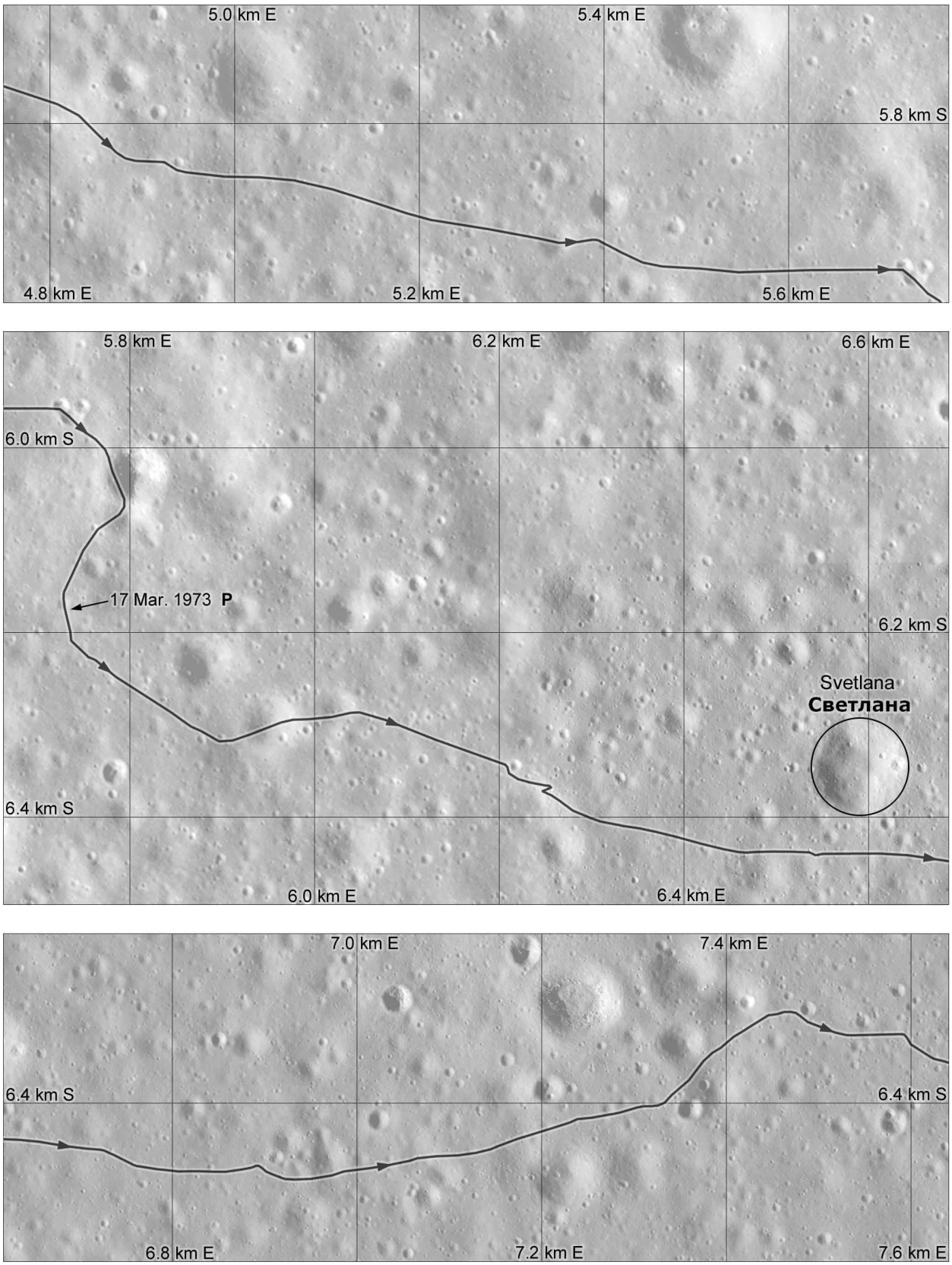


Figure 336. Lunokhod 2 route map, part 7.

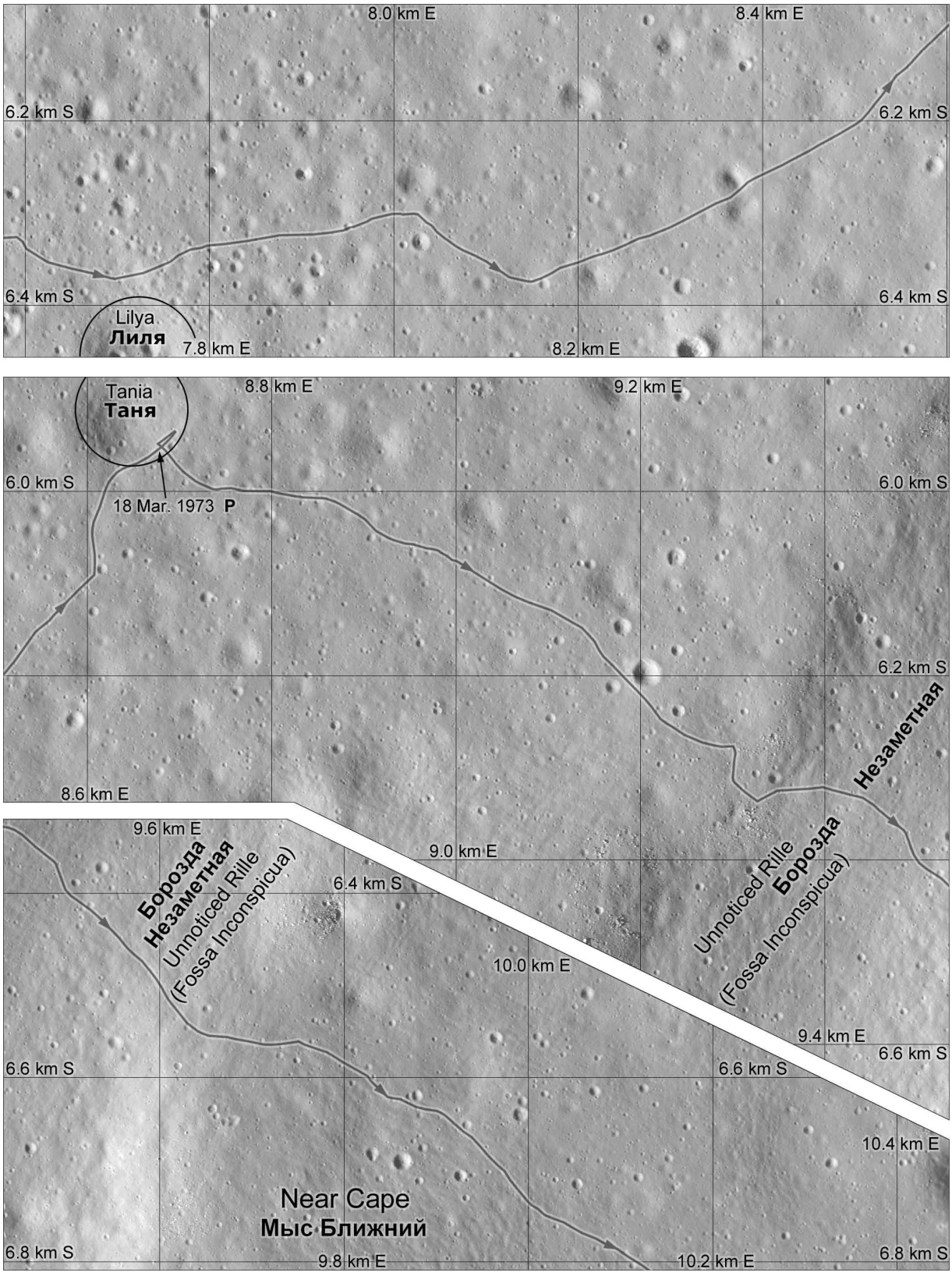


Figure 337. Lunokhod 2 route map, part 8.

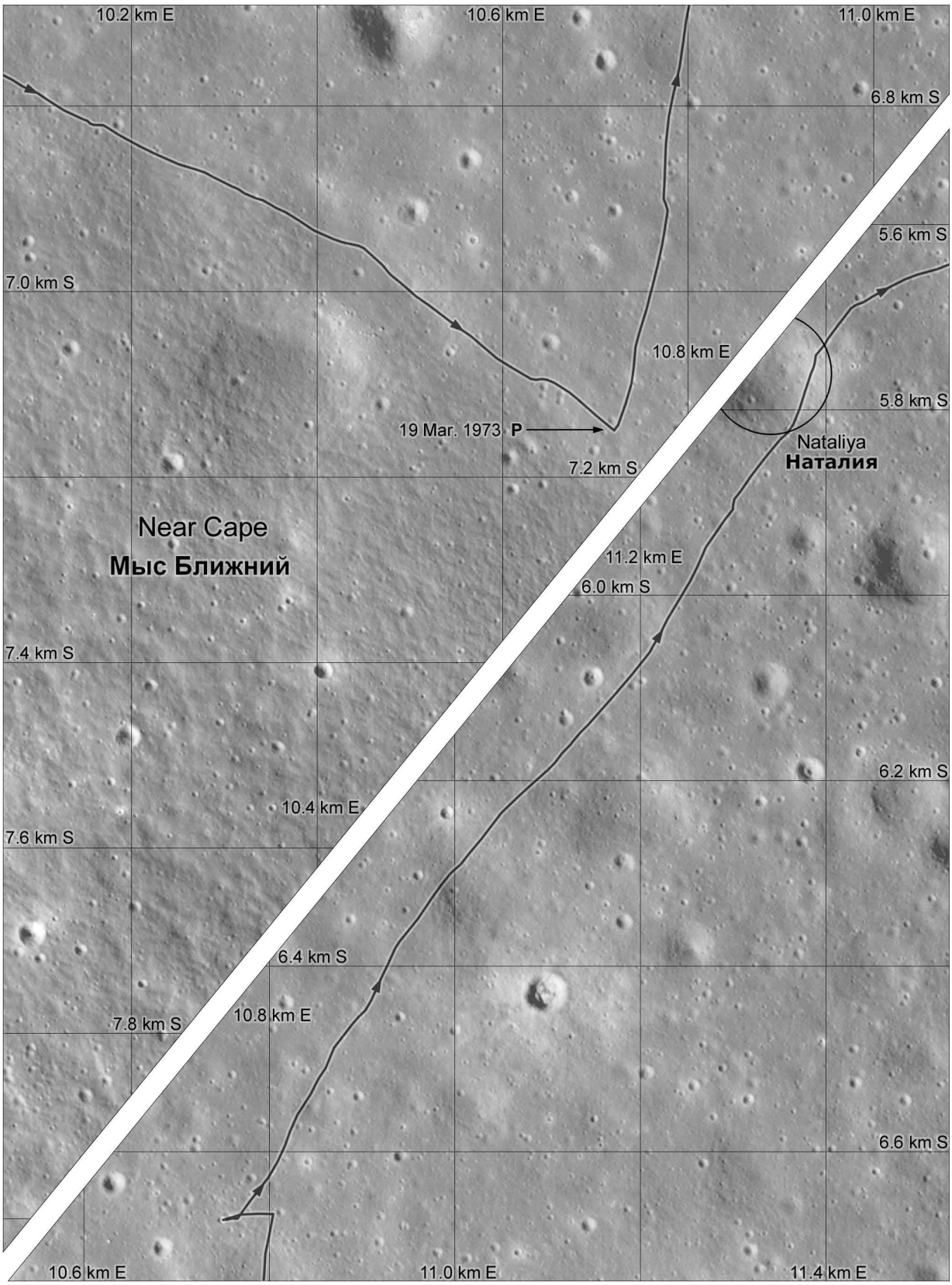


Figure 338. Lunokhod 2 route map, part 9.

The longest daily drives were on 17 March (2230 m) and 18 March (3130 m). On 19 March Lunokhod 2 was driven through a shallow trough (Unnoticed Rille, or Fossa Inconspicua), which was apparently so subdued that it was barely noticed (Figure 337). The limited coverage of the Lunokhod panoramas contributed to the difficulty in observing subtle topography. It then skirted the base of Near Cape, stopping to take panoramas (Figure 338). Then the rover was driven northeast on 20 March, through the crater Nataliya, and stopping for the night near the prominent 400 m diameter crater Kirusha, which is just outside the northern edge of Figure 339. This third day's drive had covered 16533 m, a remarkable achievement for remote rover operation.

The fourth day of activity for Lunokhod 2 began on 9 April. Every lunar day began with the rover's 'lid' being opened to expose its lining of solar cells so the batteries could be recharged after the long lunar night. The rover had stopped on the rim of a 100 m diameter crater, and now it collected X-ray data on regolith composition and maneuvered out of the complicated terrain of the crater rim. On 10 April Lunokhod 2 was driven through the subdued crater Liya and towards the edge of the prominent trough named Straight Rille or Fossa Recta (Figure 339). Magnetometer readings changed during the approach to the rim of the trough, so a roughly 500 m traverse away from and back to the rim was conducted on both sides of the trough to explore this further (Figures 339, 340, 341). The first part of this experiment was done on about 12 April (Karachevtseva *et al*. (2017) are not specific about the date), driving west-southwest, turning and driving back along the tracks to the rim of the trough.

On 16 April Lunokhod 2 was driven south along the rim of the trough, at first very close to it (Figure 340). At one point it threaded a path on a narrow ridge between the rim of Fossa Recta and a small separate trough just to its west, including the lowest elevation point of the entire traverse. The rover looped around the south end of the trough, in Circle Harbour or Round Gulf, on 17 April. After a brief excursion to the east it turned northwest to encounter the rim of the trough again on 18 April, and after a further drive of 400 m due north it stopped to take pictures of the opposite (western) wall of the trough. A zigzag path at that point (Figure 340) may show repositioning for stereoscopic imaging, or perhaps just the rover avoiding a small crater. The extensive imaging of both sides of the trough showed blocky talus on its inner slopes and may have included rare bedrock exposures (Basilevsky *et al.*, 1977).

On 19 April Lunokhod 2 drove further north, pausing at one point to back away from a crater, turn and drive around it. When it reached a point roughly opposite the starting point of the earlier magnetometer experiment (6.2 km south of the landing site, Figures 339, 341) it performed the second leg of that experiment. The rover drove about 600 m southeast and then northwest along its tracks. Back at the edge of the trough it drove north again with several maneuvers near the crater Ira (Figure 341) which probably included hazard avoidance and stereoscopic imaging. On the next day, 20 April, near the end of the lunar day, Lunokhod 2 was driven rapidly north. It entered the very shallow Ninochka crater and suddenly found itself stuck in a 6 m diameter steep-sided crater.

According to Chaikin (2004), reporting the words of Lunokhod mission scientist Alexander Basilevsky, the rover was driving northeastwards, away from the low afternoon sun which created poor visibility, and the crater was not seen until it was too late to stop. As it maneuvered to climb out, the open lid protruding behind the body of the rover struck the crater wall and its solar cells were partly covered with soil. A drop in power was noted, though this was not itself a serious problem. LRO images show the tracks at this point, helping to reconstruct the event (Figure 344). What follows is my interpretation of events.

The rover drove north and veered slightly to the west, stopping where a dark spot is visible on the track just south-southwest of the hazardous crater. The drivers had probably noticed craters A and B (Figure 344) at that point. The rover must have turned to form the dark marking, perhaps rotating so its TV cameras could be used to find a safe path. There are no panoramic images at this site to help interpret events. Then Lunokhod 2 moved northeast, down-sun, with poor visibility as commented on frequently by Apollo astronauts in such circumstances. The drivers did not see the crater until it was too late to avoid, or perhaps until they were already in it. Lunokhod 2 eventually climbed out on the east side of the crater and stopped for the night. The exact parking location for the 4th night is not certain, and Karachevtseva *et al*. (2017, map in supplementary materials) show it 200 m south of this site, with a query denoting uncertainty. Unfortunately, when the lid was closed to help keep the rover warm during the lunar night, the soil on the lid was dumped on thermal radiators intended to cool the rover during the day. This description of events seems to be the only way to have Lunokhod 2 driving down-sun just before the accident.

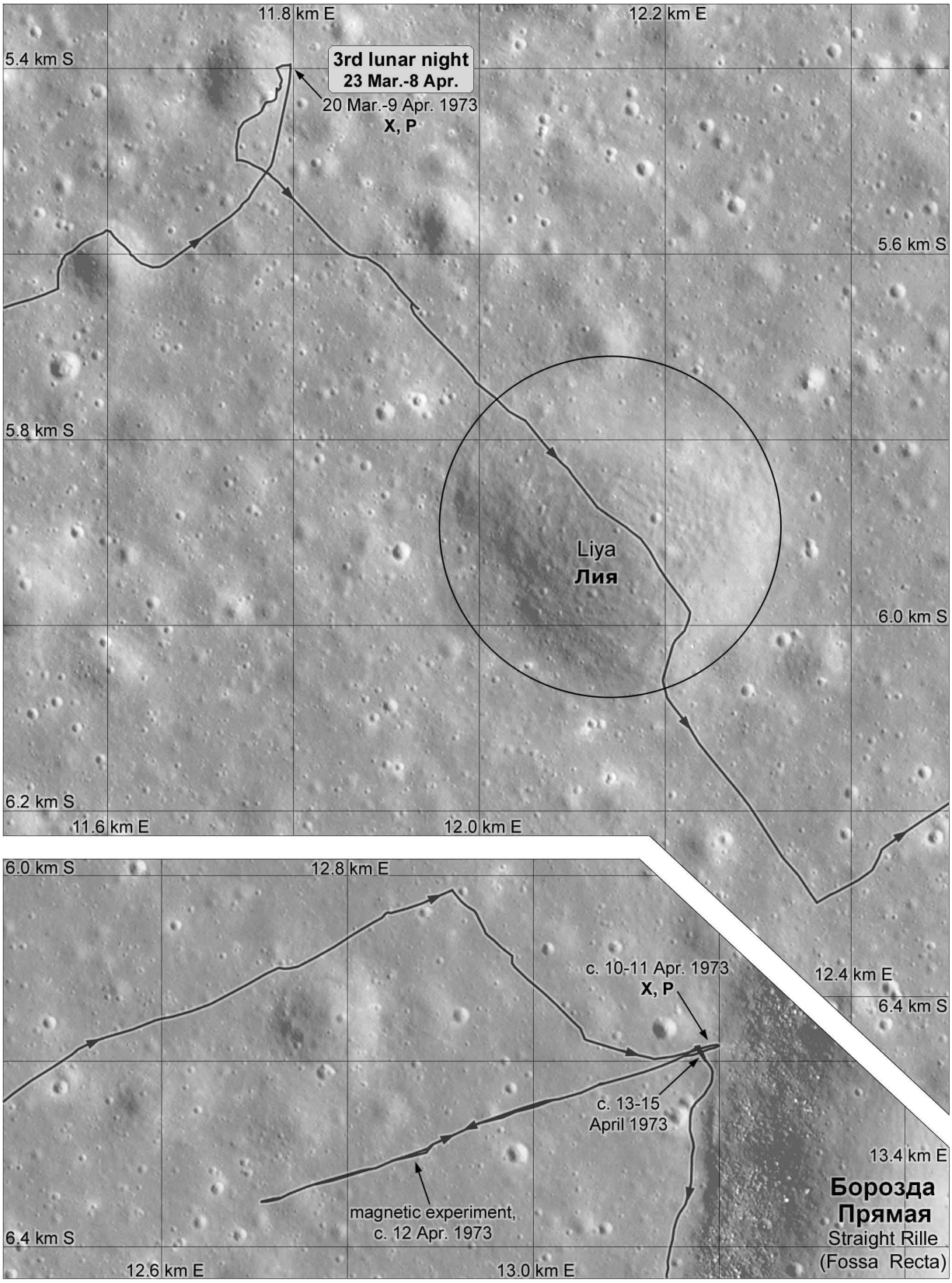


Figure 339. Lunokhod 2 route map, part 10

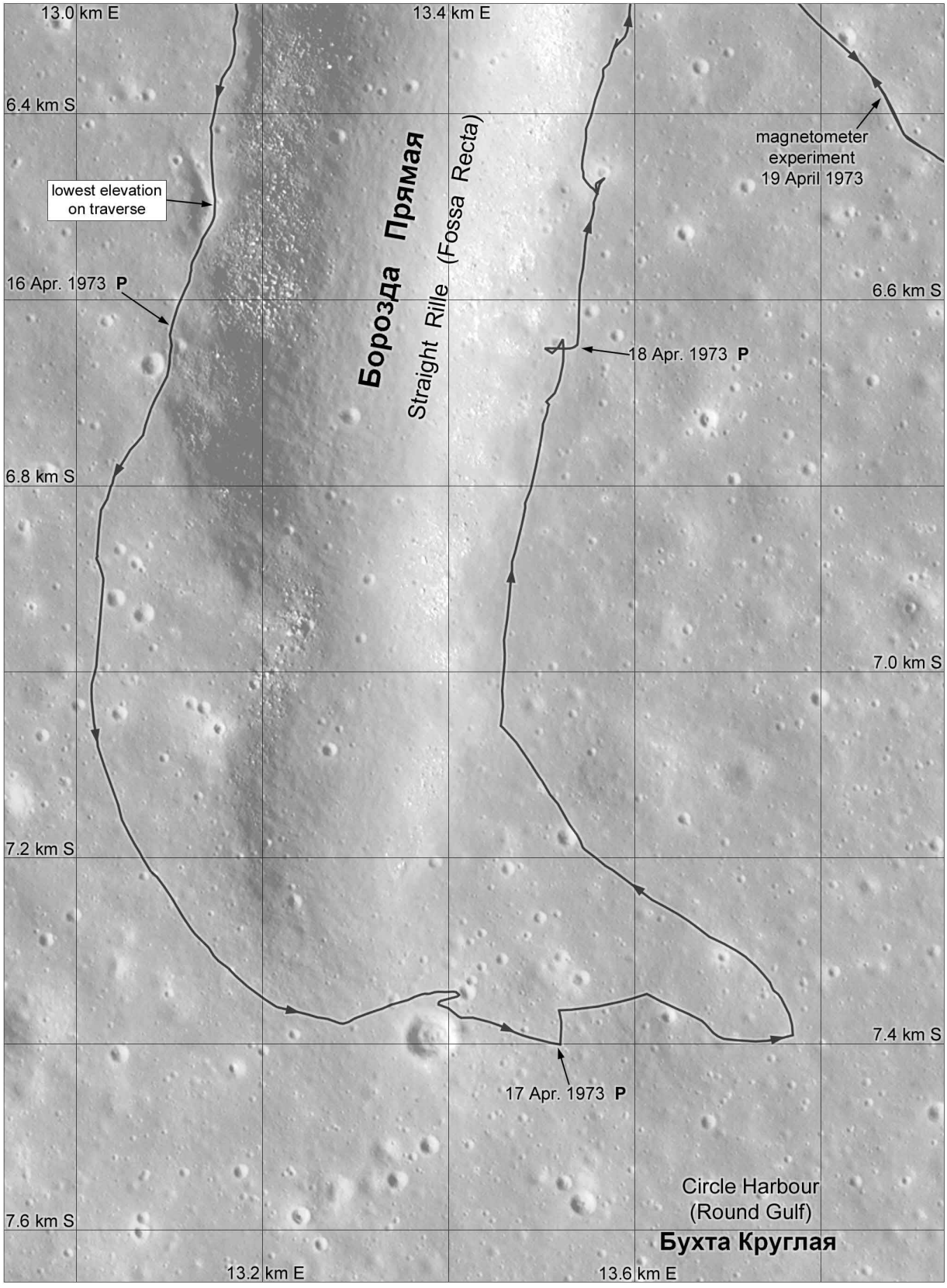


Figure 340. Lunokhod 2 route map, part 11.

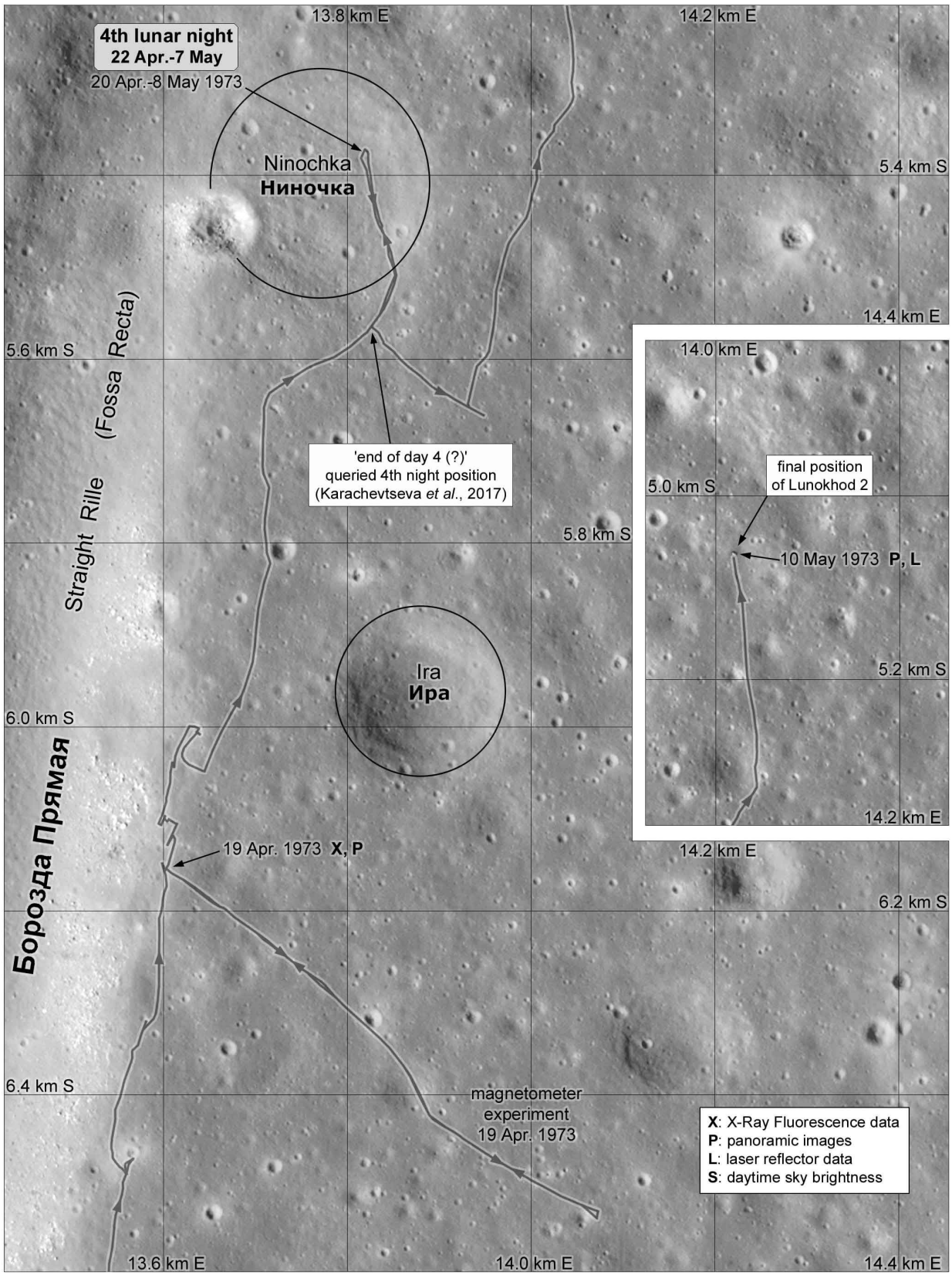


Figure 341. Lunokhod 2 route map, part 12. The 4th night location is uncertain.

The dark spot noted here was misinterpreted by P. Stooke as the rover itself when LRO images first became available in March 2010, an error whch received embarrassingly wide coverage. The fourth lunar day had included just over 9 km of driving. The Sun rose on 8 May. Lunokhod 2 was roused on the next day and driven that day and the next towards the hill called Far Cape, trying to get as far as possible before the inevitable end, but it overheated and died on 10 March, only about 400 m from Far Cape (Figure 341). Before operations ceased it was supposed to be oriented so that its laser reflector could be used in future, though if this happened at all it was only partially successful, resulting in weak laser returns.

Karachevtseva *et al*. (2017) calculated the distance travelled by Lunokhod 2 (Table 76). The '9th wheel' odometer was designed to estimate the drive distance by eliminating the effects of rover wheel slip and had protruding spikes to prevent slipping. The odometer distances in Table 76 are the figures quoted in contemporary accounts and are always a little shorter than distances calculated by GIS tools, suggesting that slip was not entirely eliminated.

Table 76. Lunokhod 2 traverse distances per lunar day

Lunar day	Dates	Distance travelled (9th wheel odometer)	Distance (GIS*)	Straight line distance from lander**
1	16-24 January 1973	1,148 m	1,299 m	1110 m
2	7-22 February 1973	9,919 m	10,034 m	7355 m
3	9-23 March 1973	16,533 m	17,622 m	12980 m
4	8-23 April 1973	8,600 m	9,136 m	14830 m
5	7-9 May 1973	880 m	1,014 m	14905 m
total		37.080 km	39.105 km	

* GIS measurements on LRO images from Karachevtseva *et al. (*2017)
** measured from Figures 280 to 291 by P. Stooke

The regolith composition varied, becoming more like highlands as they approached the hills, and then having more iron near the Straight Rille.

Luna 21 and Lunokhod 2 were auctioned with other space items at Sotheby's (New York) on 11 December 1993. The purchaser was Richard Garriott, son of Skylab astronaut Owen Garriott and a computer game entrepreneur who, in 2008, became the sixth 'space tourist' or commercial astronaut on the International Space Station. The purchase price was $68,500. Many sources mistakenly identify the auctioned items as Luna 17 and Lunokhod 1, because the original auction catalogue listed those older items. The seller, NPO Lavochkin, the Soviet-era manufacturer of the spacecraft and rover, may have substituted the later mission hardware after the initial listing, perhaps because of the historical significance of the first rover.

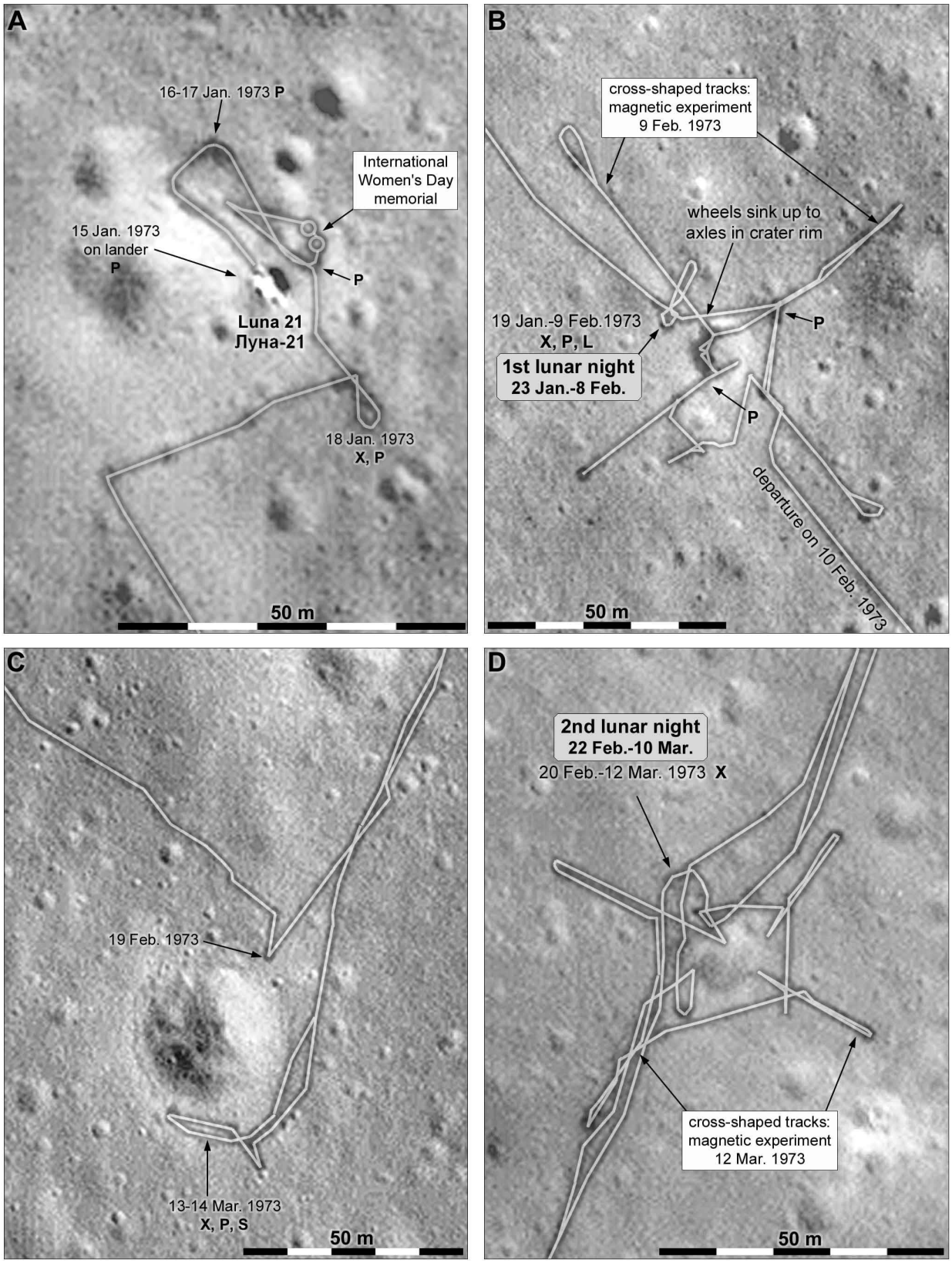


Figure 342. Enlarged maps of Lunokhod 2 activities. A: landing site. B: first night. C: south end of triple traverse. D: second night.

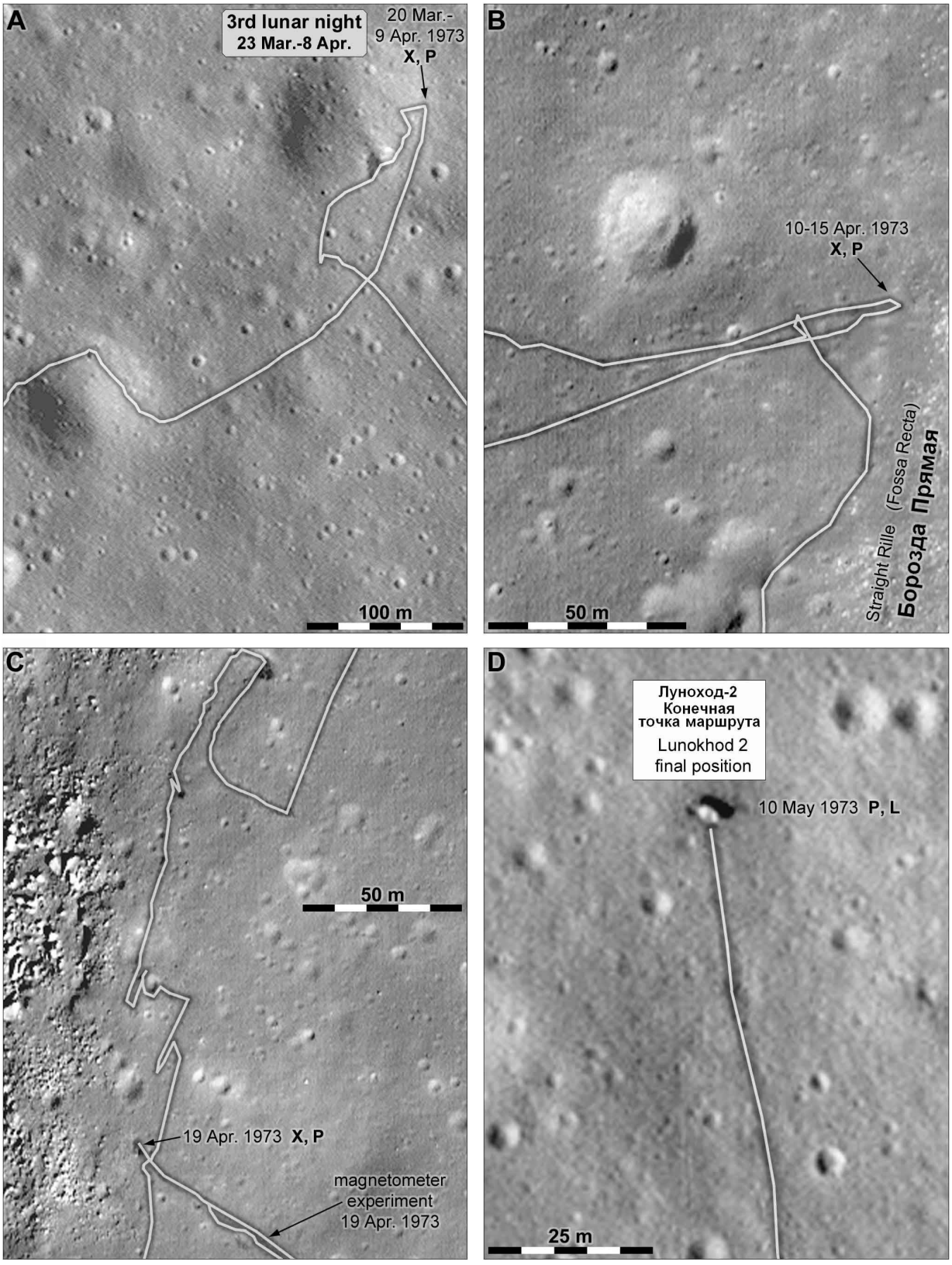


Figure 343. Enlarged maps of Lunokhod 2 activities. A: third night. B: East side of Straight Rille. C: west side of Straight Rille. D: end of traverse.

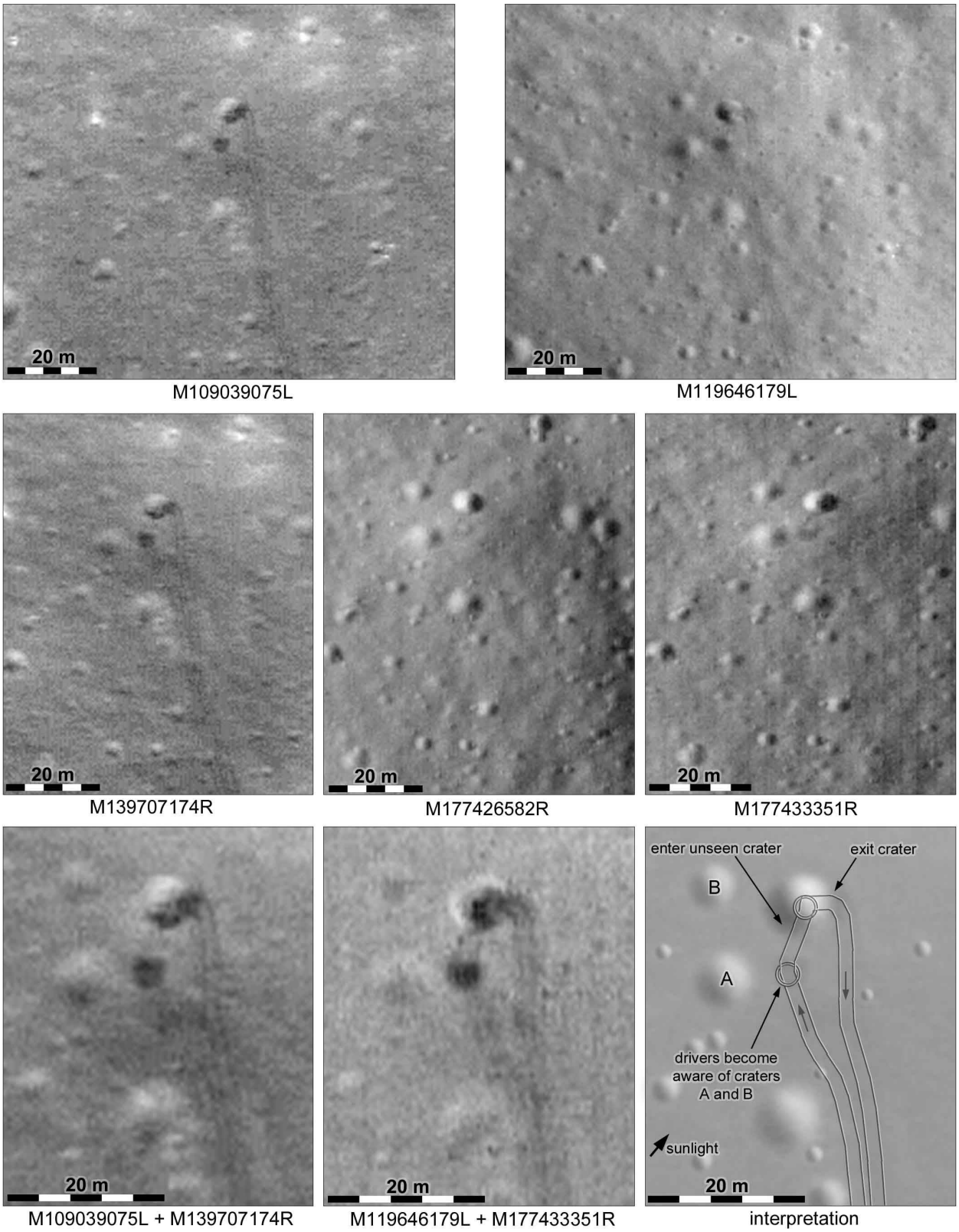


Figure 344. The Lunokhod 2 accident area. Top: five highest resolution LROC NAC images. Bottom: image pairs merged for noise suppression (left) and shadow cancelling (middle), and an interpretation of them (right).

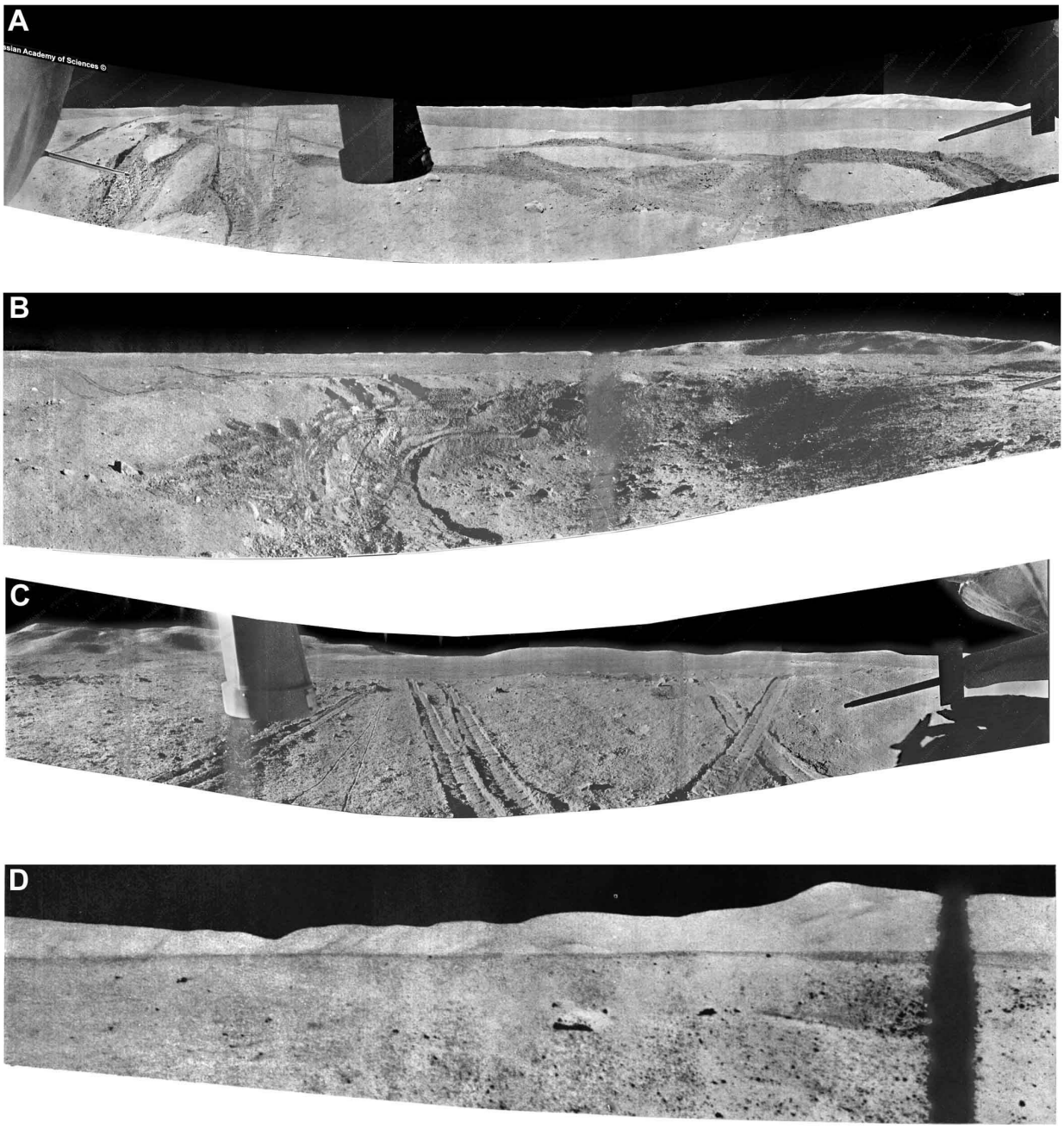
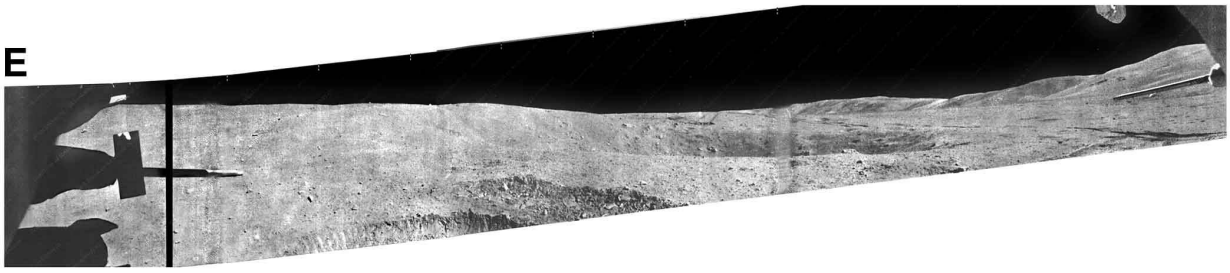


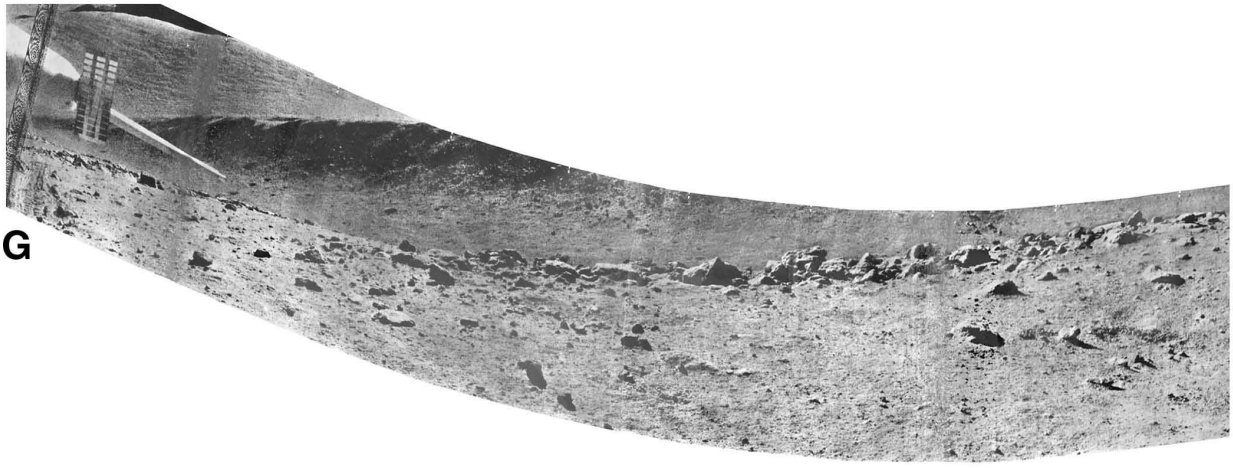
Figure 345 (across both pages). Lunokhod 2 panoramas, provided courtesy of the Russian Academy of Sciences and Roscosmos, processed by P. Stooke. A: landing site and International Women's Day memorial. B: tracks inside the crater at the site of the first magnetometer experiment, lunar day 2. C: tracks on the rim of the crater seen in B. D: Rim of Le Monnier including Near Cape (highest peak), looking southeast near the end of lunar day 1. E: southernmost point of the traverse, looking north, lunar day 3. F: part of the triple traverse, looking southeast, lunar day 3. G, H: views across Fossa Recta, late on lunar day 4.

E



F

G



H

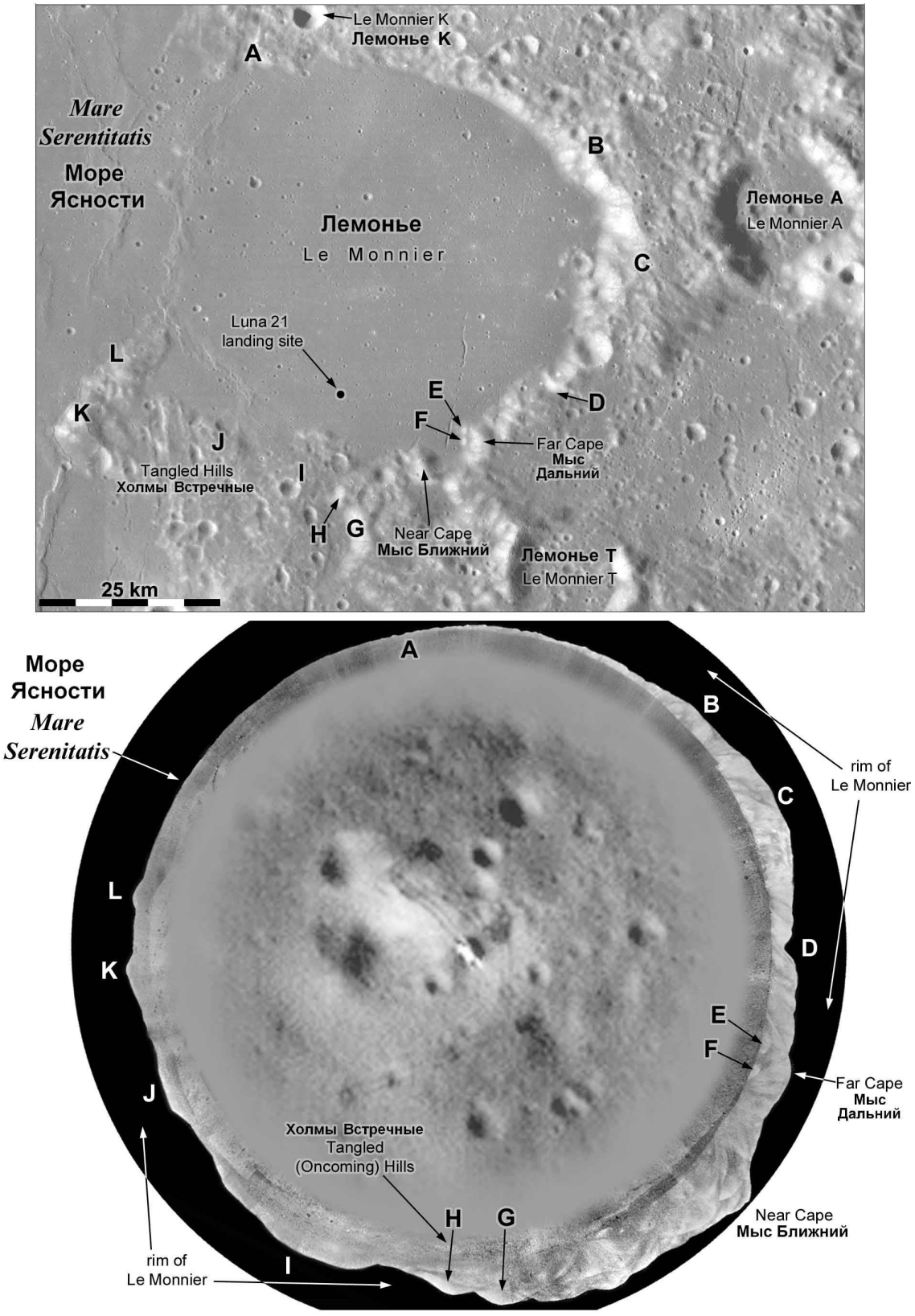


Figure 346. Lunokhod 2 landing area and a composite horizon panorama at the landing site.

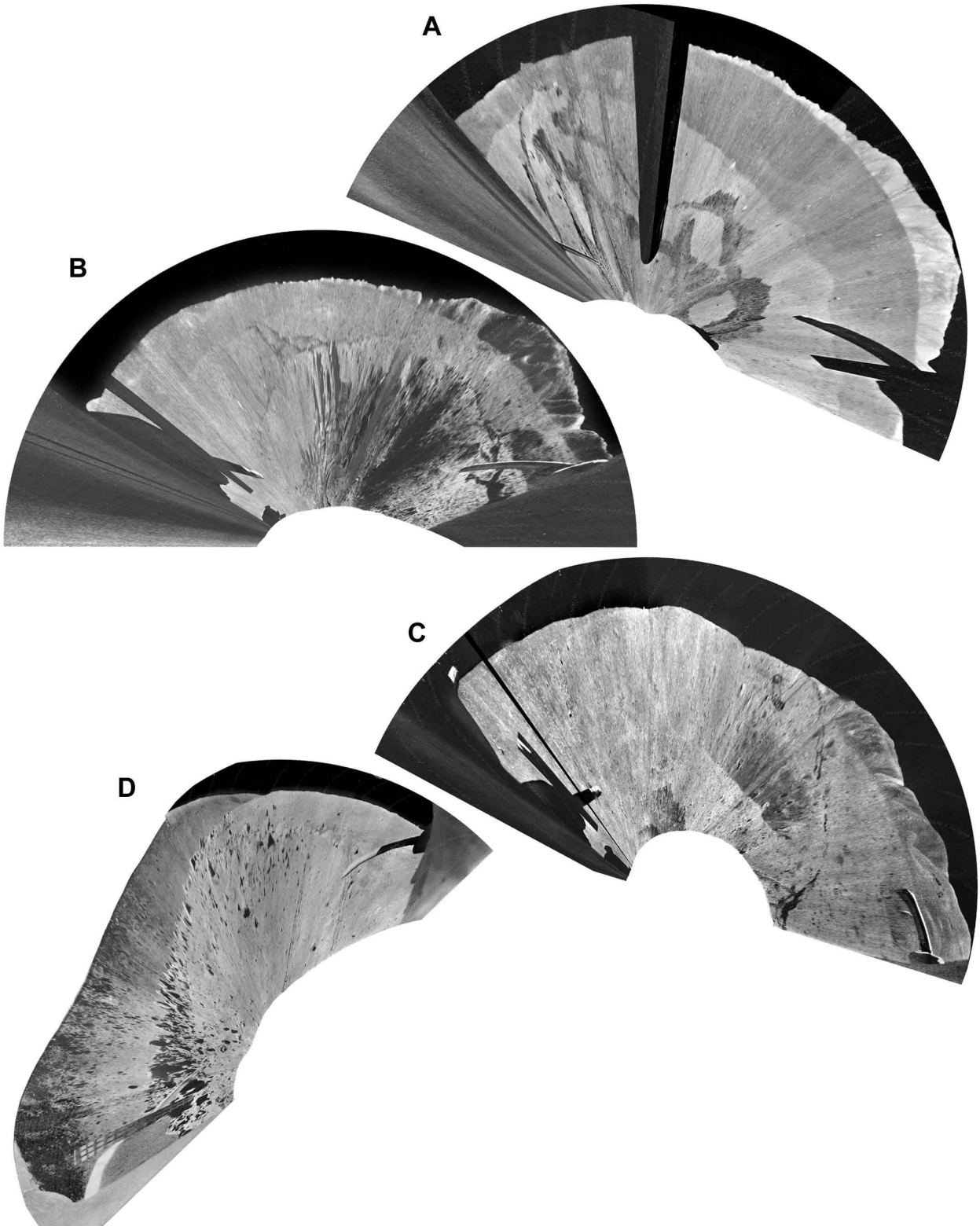


Figure 347. Lunokhod 2 panoramas projected for comparison with maps. A: landing site and International Women's Day memorial. B: crater at the site of the first magnetometer experiment, lunar day 2. C: crater at the southernmost point of the traverse, lunar day 3. D: rim of Fossa Recta, lunar day 4.

Figure 345 shows some representative Lunokhod 2 panoramas. 345A was taken near the landing site on lunar day 1, looking out to the flat horizon where Mare Serenitatis meets Le Monnier crater. The International Women's Day '8' marking in the tracks is shown. Figure 345B shows tracks inside the crater where the first magnetometer experiment occurred, taken on lunar day 2. 345C shows tracks on the rim of that crater and 345D is a more distant vew of the same crater during approach to it on lunar day 1. E is the southernmost point on the traverse, looking north across the crater shown in Figure 342C during lunar day 3. Figure 345F is part of the triple traverse imaged on lunar day 3, 345G and 345H are views across Fossa Recta, taken on lunar day 4. All images except F have been reprojected to make the horizons level. Original images courtesy Sternberg State Astronomical Institute and MIIGAiK (A to D) and USGS Flagstaff (E to H). Panoramas are also available, courtesy of Roscosmos, at https://www.planetology.ru/panoramas/lunokhod2.php.

Figure 346 shows a composite of several panoramas taken at or very near the landing site, combined to give a full horizon panorama. The foregrounds do not match and have been removed and replaced by an LRO view of the landing site. This appears to be the only place where a full horizon panorama is possible for either Lunokhod. Figure 347 shows four panoramas very roughly projected into semicircles to give a more map-like geometry.

The first attempt to fly a Lunokhod on 19 February 1969 (named Luna 1969A rather than designating its purpose specifically) was also targeted at Le Monnier. Lunokhod 3 was built but not flown in 1977 as intended. It had a short moveable arm which could place instruments on or near the surface. Funding for lunar missions had now disappeared and its launch vehicle was used elsewhere, so the rover stayed on Earth. It is on display at the NPO Lavochkin museum in Moscow. Its landing target has not been disclosed and perhaps was never chosen.

Beyond Lunokhod there were thoughts about a considerable advance on the recent series of rovers and sample return landers. It was called Sparka ('pair') as it would combine a Lunokhod-like rover with a sample-return craft. The Sparka rover would collect samples with its robotic arm and deliver them to a waiting sample-return vehicle. This somewhat resembles NASA's plan for Mars sample return with samples collected by the Perseverance rover and intended to be brought to Earth by (as of January 2025) a yet to be selected vehicle. If the sites and sampling targets were carefully chosen its results might have approached the scientific value of the early Apollo missions (Chaikin, 2004; Harvey, 2007).

Anonymous, 2015. Along the rille of Le Monnier Bay. Blog post, http://ourairports.biz/?p=3045.

Basilevsky, A. T., Florensky, C. P. and Ronca, L. B., 1977. A possible lunar outcrop: a study of Lunokhod-2 data. *The Moon*, v. 17, pp. 19-28.

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Dolginov, Sh. Sh., Yeroshenko, Ye. G., Zhuzgov, L. N. *et al*., 1977. Magnetic field data in Le Monnier Bay according to data of Lunokhod 2. In Pomeroy, J.H. and Hubbard, N.J. eds., 1977. *The Soviet-American Conference on Cosmochemistry of the Moon and Planets: A Conference Held in Moscow, USSR, June 4-8, 1974*. NASA-SP-370-PT-1, pp. 433-442.

Florensky, C. P., Basilevsky, A. T., Bobina, N. N. *et al.*, 1978. The floor of crater Le Monier: a study of Lunokhod 2 data. *Proceedings of the 9th Lunar and Planetary Science Conference*, Volume 2 (A79-39176 16-91), pp. 1449-1458. New York: Pergamon Press, Inc.

Gao, T., Xue, L. and Ye, S., 2024a. Near-infrared lunar laser ranging: Research on pointing error of Lunokhod 2 corner reflector based on effective echo signal broadening. *Infrared Physics & Technology*, v. 137, 105095. https://doi.org/10.1016/j.infrared.2023.105095

Gao, T., Xue, L. and Feng, J., 2024b. Lunar laser ranging: The pointing error analysis to Lunokhod 1 and Lunokhod 2. *Icarus*, v. 407, 115792. https://doi.org/10.1016/j.icarus.2023.115792

Gromov, V., Kemurdjian, A., Bogatchev, A. *et al*., 2003. Lunokhod 2 - a retrospective glance after 30 years. In EGS-AGU-EUG Joint Assembly, 6-11 April 2003, Nice, France, p. 14528.

Harvey, B., 2007. Soviet and Russian Lunar Exploration. Springer Praxis New York, NY. https://doi.org/10.1007/978-0-387-73976-2

Karachevtseva, I. P., Kozlova, N. A., Kokhanov, A. A. *et al.*, 2017. Cartography of the Luna-21 landing site and Lunokhod-2 traverse area based on Lunar Reconnaissance Orbiter Camera images and surface archive TV-panoramas. *Icarus*, v. doi: 10.1016/j.icarus.2016.05.021.
Karachevtseva, I. P. and Rodionova, Zh. F. (eds), 2016. Map of "Luna-21" landing region and the "Lunokhod-2" route. Scale 1:25,000. Moscow, Russia: Moscow State University of Geodesy and Cartography (MIIGAiK), MIIGAiK Extraterrestrial Laboratory.
Severny, A. B., Terez, E. J. and Zvereva, A. M., 1975. The measurements of sky brightness on Lunokhod-2. *The Moon*, v. 14, pp. 123-128.
Vernov, S. N., ed., 1978. *Uspekhi Sovetskogo Soyuza v issledovanii kosmicheskogo prostranstva*. Moscow: Nauka.
Wagner, R.V., Nelson, D.M., Plescia, J.B. *et al.*, 2017. Coordinates of anthropogenic features on the Moon. *Icarus*, v. 283, pp. 92-103. https://doi.org/10.1016/j.icarus.2016.05.011
Zak, A., 2018. The day a Soviet moon rover refused to stop. *Smithsonian Air and Space Magazine*, 18 January 2018. https://www.smithsonianmag.com/air-space-magazine/time-soviet-moon-rover-refused-stop-180967884/

10 June 1973: Explorer 49 (RAE-B)

Explorer 49 was also called Radio Astronomy Explorer B (RAE-B) or RAE-2. As the name suggests it was not a lunar exploration mission, but it conducted its radio astronomy program from lunar orbit. A companion mission, RAE-A (Explorer 38), was launched on 4 July 1968 and orbited Earth, but found the planet to be noisier than expected with both natural and artificial emissions. Explorer 49 was placed around the Moon to reduce this noise. A panoramic camera took images to confirm spacecraft orientation and to monitor the deployment of its long antennae, which formed an X-shape 500 m across. The upper half of the X ('upper V'), two antennae each 229 m long, pointed away from the Moon. The 'lower V', pointing towards the Moon, was operated at 183 m length until November 1974 when it was extended to 229 m. A 37 m dipole antenna was deployed across the middle of the X configuration perpendicular to its long axis, and a 129 m boom was deployed to dampen oscillations of the large structure (Alexander *et al.*, 1975).

The 328 kg spacecraft was launched from Cape Canaveral, Florida at 14:13 UT on 10 June 1973 and entered lunar orbit on 15 June. Its orbit was near-circular at an altitude of about 1060 km, inclined 56º to the equator. It transmitted data until August 1977. Explorer 49's orbit was high enough that it is probably still in lunar orbit (Powell 2003).

The Explorer 49 camera was a 4-bit panoramic scanning device. It produced 2160 by 512 pixel images which were heavily compressed for transmission. Over 100 images were taken and displayed on monitors in mission control at Goddard Space Flight Center (Miller and Lynch, 1976). The only known published example is shown in Figure 348A, with the Moon at left (cut by compression artifacts) and parts of the spacecraft across the rest of the image.

Alexander, J. K., Kaiser, M. L., Novaco, J. C. *et al*., 1975. Scientific instrumentation of the Radio-Astronomy-Explorer-2 satellite. *Astronomy and Astrophysics*, v. 40, no. 4, p. 365-371.
Miller, W. H. and Lynch, T. J., 1976. On-board image compression for the RAE lunar mission. *IEEE Transactions on Aerospace and Electronic Systems*, AES-12, May 1976, pp. 327-335.
Powell, D., 2003. The Moon's own moons. *Astronomy Now*, v. 17, no. 9, September 2003, pp. 38-39.

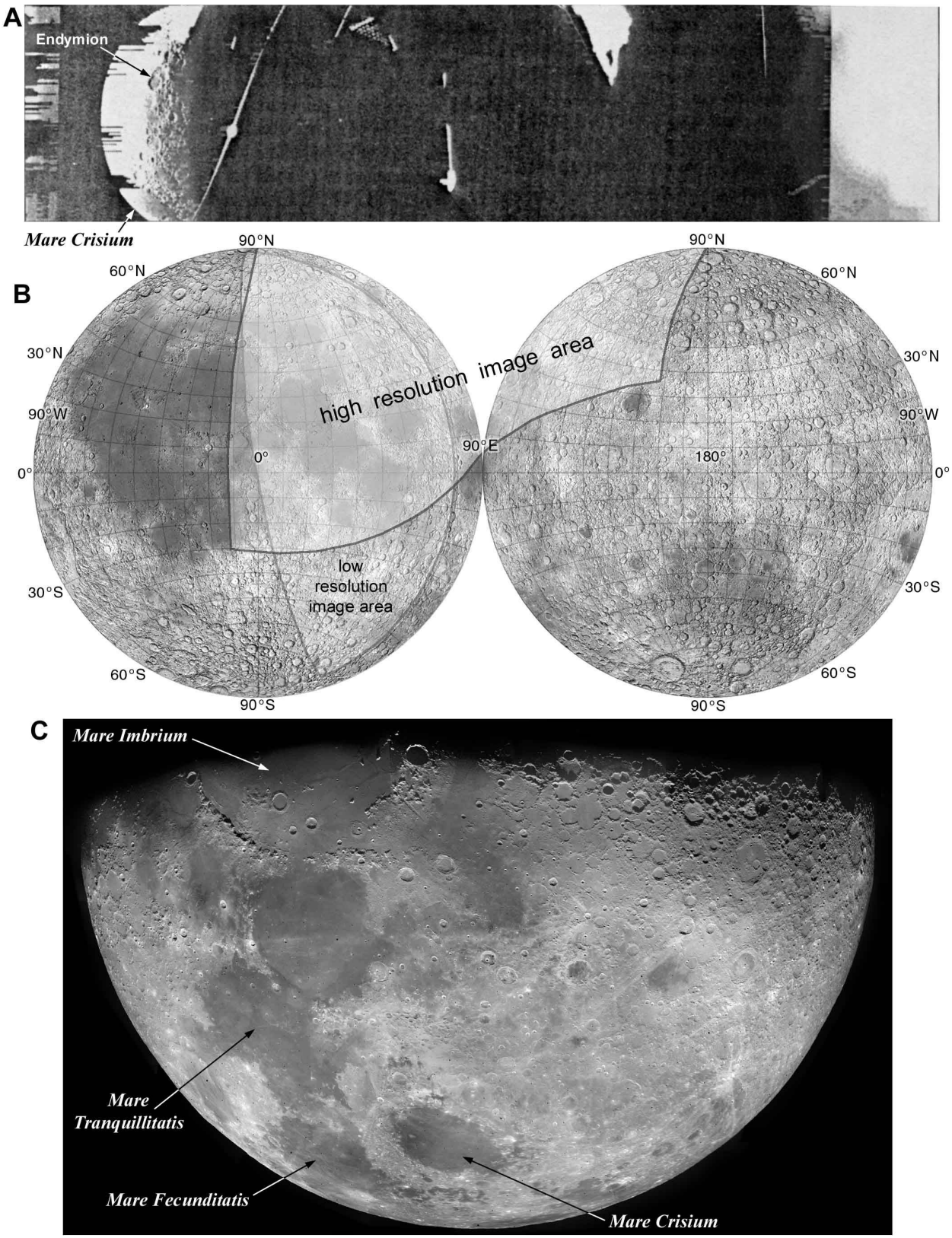

Figure 348. Explorer 49 (RAE-B) and Mariner 10 images. A: Explorer 49 image including the Moon and parts of the spacecraft. B: Mariner 10 image coverage. C: Mariner 10 high resolution mosaic.

3 November 1973: Mariner 10

Mariner 10 was launched from Cape Canaveral, Florida at 05:45 UT on 3 November 1973, spent 25 minutes in a parking orbit, and then was placed on a trajectory that passed the Moon on its way to Venus and Mercury. Several hundred images making up six photomosaics of the Moon were taken during the lunar flyby (Giberson and Cunningham, 1975).

Mariner 10's camera and ultraviolet spectrometer observed Comet Kohoutek during the cruise to Venus. The spacecraft flew past Venus on 5 February 1974 about 4200 km above the surface. This was the first planetary gravity assist, and it also provided important image data for studies of Venus cloud dynamics.

Mariner 10 passed Mercury at 20:46 UT on 29 March 1974, the first spacecraft to visit that planet, only 705 km above the strikingly moonlike surface. After two solar orbits by Mercury and one by the spacecraft, they again passed on 21 September 1974 at a distance of 47000 km, obtaining more images to fill most of a gap between areas covered during the first encounter. A third flyby on 16 March 1975 at a height of only 327 km provided a small number of additional images of the same area seen on the first flyby. Finally on 24 March 1975 the attitude control fuel was exhausted and the mission ended.

The Mariner 10 images of the Moon increased coverage of the northern farside near the north pole, a region seen poorly by Lunar Orbiter (Robinson *et al.*, 1993). The new images were good enough to contribute to updated mapping by USGS, which had taken over the task after the Department of Defense abandoned lunar mapping. They included multispectral images (Robinson *et al.*, 1992).

The area imaged by Mariner 10 is mapped in Figure 348B. Figure 348C is a mosaic of 20 separate frames of the northern hemisphere, roughly centred on 80º E. As Mariner 10 receded from Earth it also observed parts of the southern hemisphere at very low resolution. Some areas near the limb are distorted to accommodate views from slightly different perspectives. Images are from NASA's Planetary Data System, mosaicked and processed by P. Stooke.

Giberson, W. E. and Cunningham, N. W., 1975. Mariner 10 mission to Venus and Mercury. *Acta Astronautica*, v. 2, nos. 7–8, pp. 715-743

Robinson, M.S., Hawke, B.R., Lucey, P.G. and Smith, G.A., 1992. Mariner 10 multispectral images of the eastern limb and farside of the Moon. *Journal of Geophysical Research: Planets*, v. 97, E11, pp.18265-18274.

Robinson, M. S., Hawke, B. R., Edwards, K. et al., 1993. Preliminary results from Mariner 10: High resolution images of the Moon. Presented at the 24th Lunar and Planetary Science Conference, Houston, Texas, 15-19 March 1973. Abstract no. 1207.

29 May 1974: Luna 22

This heavy lunar orbiter, similar to Luna 19, was launched from Baikonur on a Proton booster at 08:57 UT on 29 May 1974. The 4000 kg spacecraft made one course correction on 30 May and entered lunar orbit on 2 June. Its 220 km high circular orbit was inclined 20º to the equator. After a week it moved to a 25 by 245 km orbit, allowing imaging and radar altimetry from the lower altitude. This mapping phase lasted only four days, and then the orbiter moved back up to a more stable 180 by 300 km orbit for a five month long observatory phase. Here it monitored radiation, micrometeorites, magnetic fields, gamma ray emissions and surface composition.

Orbital tracking was used to reveal further details of mascons (Figure 84C in Chronicle part 2). On 11 November Luna 22 raised its orbit to a 170 by 1437 km ellipse, and on 2 April 1975 it was moved to a 200 by 1410 km orbit. These adjustments allowed the radiation and micrometeorite detectors to sample different parts of the lunar environment. The fuel was exhausted by 2 September 1975 and the mission ended in November 1975.

As with Luna 19, some of the instruments on board were apparently experimental, and there was no systematic mapping of the lunar surface. The imaging system was similar to that of Luna 19, scanning from horizon to horizon and, at least potentially, from terminator to terminator. Both missions were probably testing cameras for missions to Mars or other destinations because their images were inadequate for useful lunar research.

Figure 349A shows an example of a Luna 22 image, courtesy of MIIGAiK. The panoramic image shown here extends across the central highlands of the nearside from roughly 8º E to 32º E including the crater Torricelli (filled with shadow at far right). The narrow horizontal line is caused by a spacecraft component intruding into the field of view of the scanner. Figure 349B is a roughly rectified view of the same image. Ten imaging sessions are supposed to have been undertaken, but few images were released. Those known to the author are mapped in Figure 349C. The maximum resolution was several hundred m/pixel, not adequate for detailed landing site selection or to plan surface activities.

Figure 349C is a map of known image coverage. Most images used to compile this map were scanned from a set at USGS Flagstaff, and others were provided by Jeanna Rodionova (Sternberg State Astronomical Institute, Moscow) and Don P. Mitchell. Since this includes only the images known to the author it may not be complete. A small box at 13º S, 73º W (Figure 349D) represents additional Luna 22 observations using bistatic radar to create images of the surface (Zaitsev *et al*., 1977). Three observations were made on unspecified dates over Rocca crater. The results were topographic profiles and low resolution reflectivity maps. The paper showed three reflectivity maps, which have been combined in Figure 349E and superimposed on a map. The image includes an attempt (by P. Stooke) to remove north-south ambiguity. Brighter areas are rougher than their surroundings (e.g. ejecta of Rocca L) or are slopes facing the radar (a ridge and several crater rims). This observation should probably be seen as a test for future use on other planets, and in fact the same process was used at Venus by the Venera 9 and 10 missions only a year later. At Venus absolutely nothing was known about the surface features of the probed areas at the time so these Luna 22 observations offer a kind of 'ground truth'.

Results of the Luna 22 radar altimetry experiment are shown in Figure 350A. Only these four profiles are known to exist (Tyuflin *et al.*, 1976), enough for topographic profiling of specific features but inadequate for regional mapping. The vertical bar at the left end of each profile represents 5 km of elevation, and each profile is about 1100 km long. Apollo altimetric measurements (Figure 323B) did not cover this area.

The altimeter was also used to probe the ionosphere, as Luna 19's had done. Three observations were reported by Vyshlov *et al*. (1976), made on 18, 19 and 21 August 1974. The locations of the occultation points are not known.

Tyuflin, Y. C., Timofeev, Y. C., Alexashin, E. P. and Ostrovskii, M. B., 1976. Nekotorie resultat radioprofilirovaniya s avtomaticheskoi stantsii Luna-22. *Kartografirovanie Lune i Planet*, pp. 54-58. MIIGAiK, Moscow.

Vyshlov, A.S., Savich, N.A., Vasilyev, M.B. *et al*., 1976. Some results of cislunar plasma research. in Ness, N. F. (ed.), 1976. *Solar-Wind interaction with the planets Mercury, Venus, and Mars*. Proceedings of a Bilateral Seminar of the US/USSR Joint Working Group on Near-Earth Space, the Moon, and Planets, Moscow, USSR, 17-21 November 1975. NASA-SP-397, pp. 81-85.

Zaitsev, A. L. *et al*., 1977. Bistatic radar surveillance of the moon, using a modulated signal. *Radiotekhnika i Elektronika*, v. 22, pp. 2097-2104.

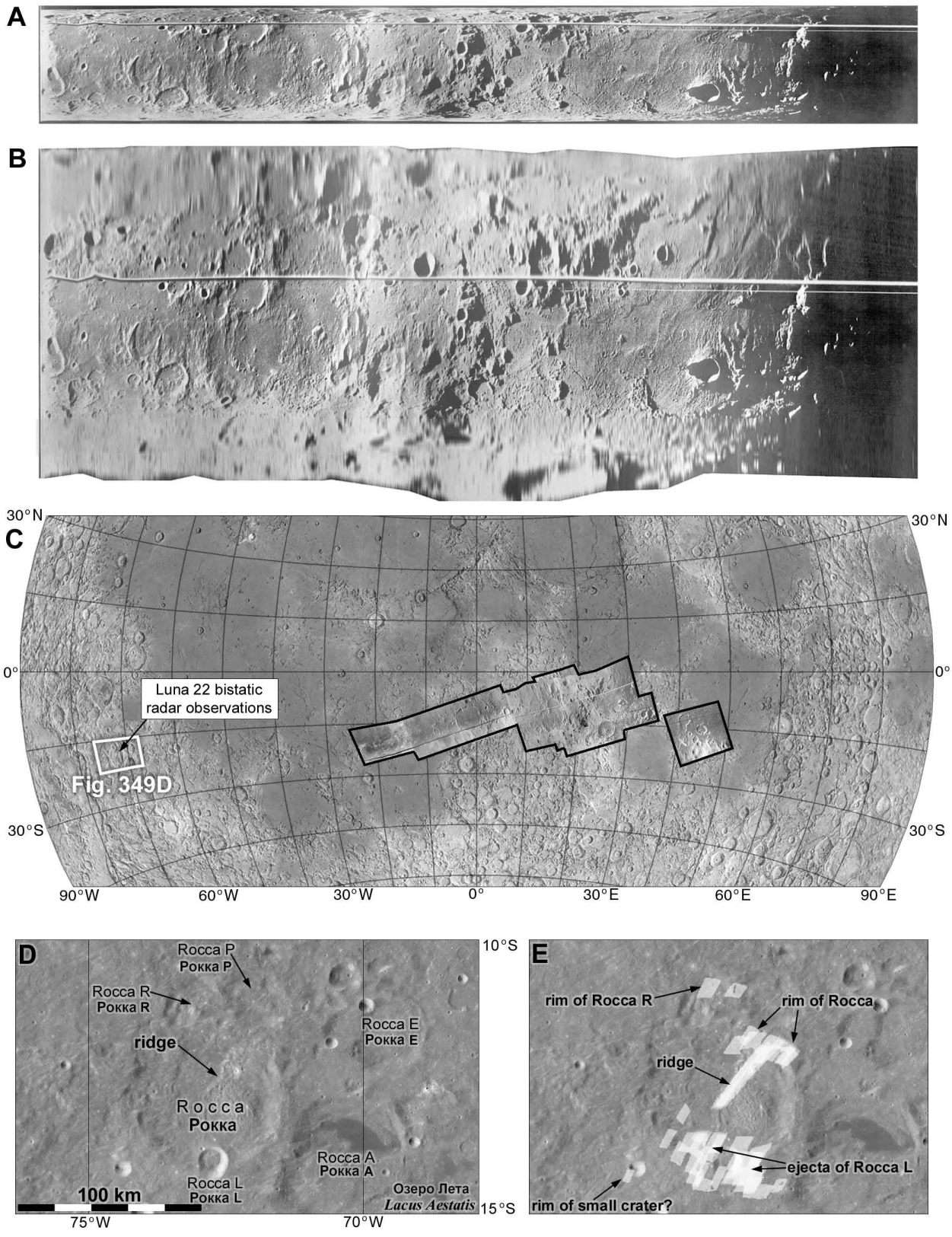

Figure 349. Luna 22 images. A: Image strip including Torricelli crater and Sinus Asperitatis. B: roughly perspective-projected version of A. C: coverage of all known Luna 22 images. D: bistatic radar area. E: bistatic radar image.

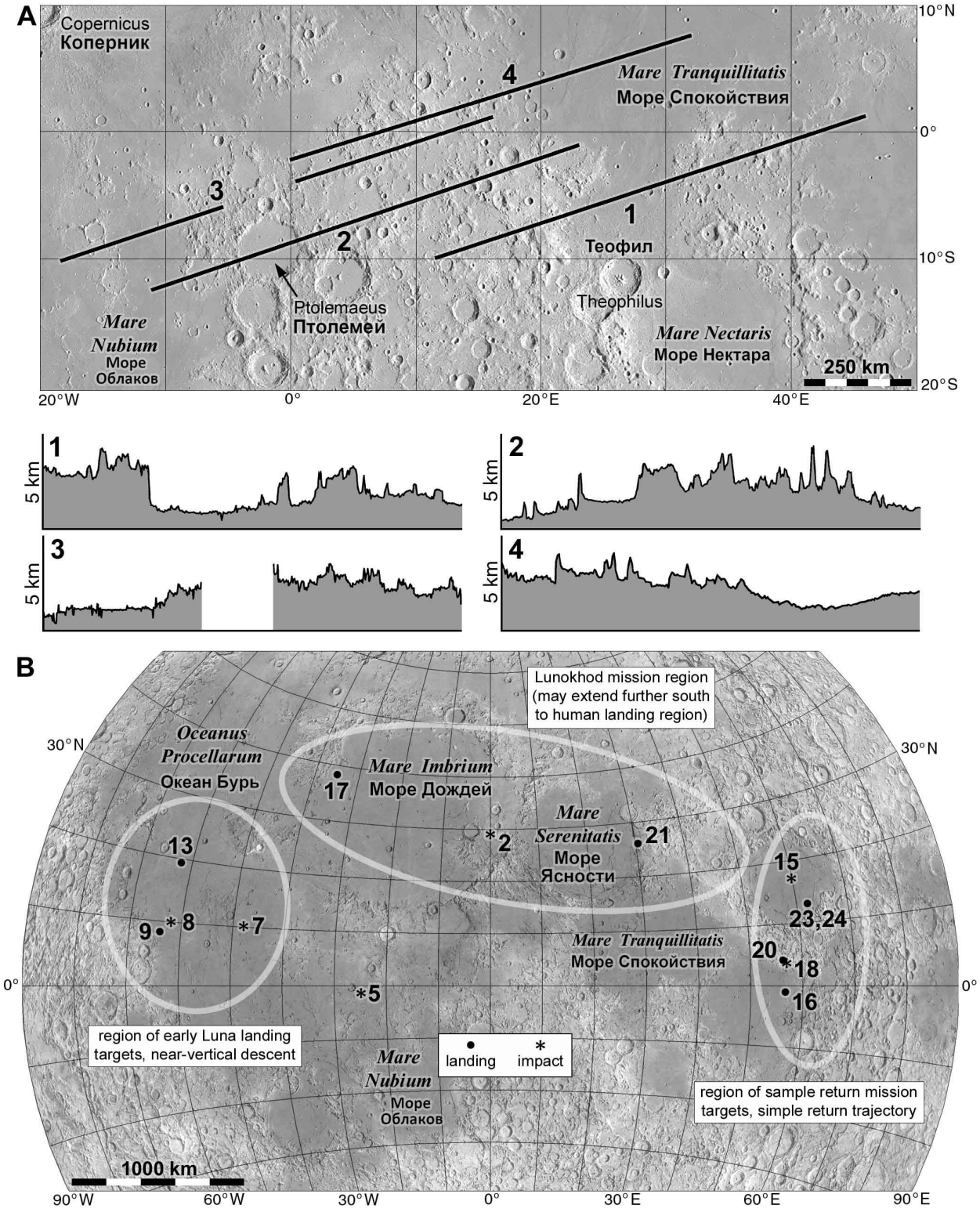

Figure 350. Luna 22 altimetry and Soviet landing areas. A: ground tracks of Luna 22 altimetric data and the topographic profiles. B: target areas of different classes of Soviet lunar landers.

28 October 1974: Luna 23

Both Luna 16 and Luna 20 had experienced difficulties with their sampling drills. A new drill, attached to the side of the descent stage rather than carried on a hinged arm, was designed for future missions. It was more robust and could apply more pressure than the previous version. The camera was removed to accommodate it, and because the fixed drill no longer offered the flexibility of adjusting the drill site based on the images.

Luna 23, weighing 5600 kg with its upper stage, was launched from Baikonur on a Proton booster at 14:30 UT on 28 October 1974, entered an Earth parking orbit, and then was sent to the Moon. After a trajectory correction on 31 October the vehicle entered a 94 by 104 km lunar orbit inclined 138º to the equator on 1 November. The orbit was adjusted over four days to drop its low point to only 17 km, and on 5 November the final descent began. Luna 23 landed intact but roughly, damaging the drill so no sample could be collected. The other systems functioned and controllers communicated with the spacecraft for four days until its batteries overheated or were exhausted. The sample return capsule was not launched but the drill was said to have been operated for test purposes.

The region accessible to these sample return missions (Figure 350B) contained three principle sampling targets, Mare Fecunditatis, the circum-Crisium highlands, and Mare Crisium, and with the first two accomplished the third was eagerly sought. The Luna 23 landing site was given as 13° N, 62° E (LePage, 1996), 18° N, 58° E (Sven Grahn website at http://www.svengrahn.pp.se/histind/Luna1524/Lun1524.htm) and the National Geographic Society maps showed it at 14° N, 57° E. LePage's estimate was roughly correct.

The landing site was eventually identified in images from LRO (Plescia, 2012) at 12.667° N, 62.151° E (Wagner *et al*., 2017). The images showed that Luna 23 landed immediately adjacent to a white object, initially suggested to be a rock which might have damaged the lander or its drill. In low altitude images taken in 2012 the lander was seen more clearly and interpreted to have fallen over on landing, the white object being the sample return capsule. Lavochkin, the manufacturer, said it landed with too great a horizontal velocity on a slope and fell over.

A controversy over the LRO identifications of Lunas 23 and 24 is described in association with Luna 24.

LePage, A., 1996. Ahead of their time: the Soviet lunar program of the Seventies - Part II. *Electronic Journal of the Astronomical Society of the Atlantic*, v. 7, no. 2, 1996.

Plescia, J., 2012. Mare Crisium: failure then success. Blog post, 16 March 2012. https://www.lroc.asu.edu/images/461

Wagner, R.V., Nelson, D.M., Plescia, J.B. *et al*., 2017. Coordinates of anthropogenic features on the Moon. *Icarus,* v. 283, pp. 92-103. https://doi.org/10.1016/j.icarus.2016.05.011

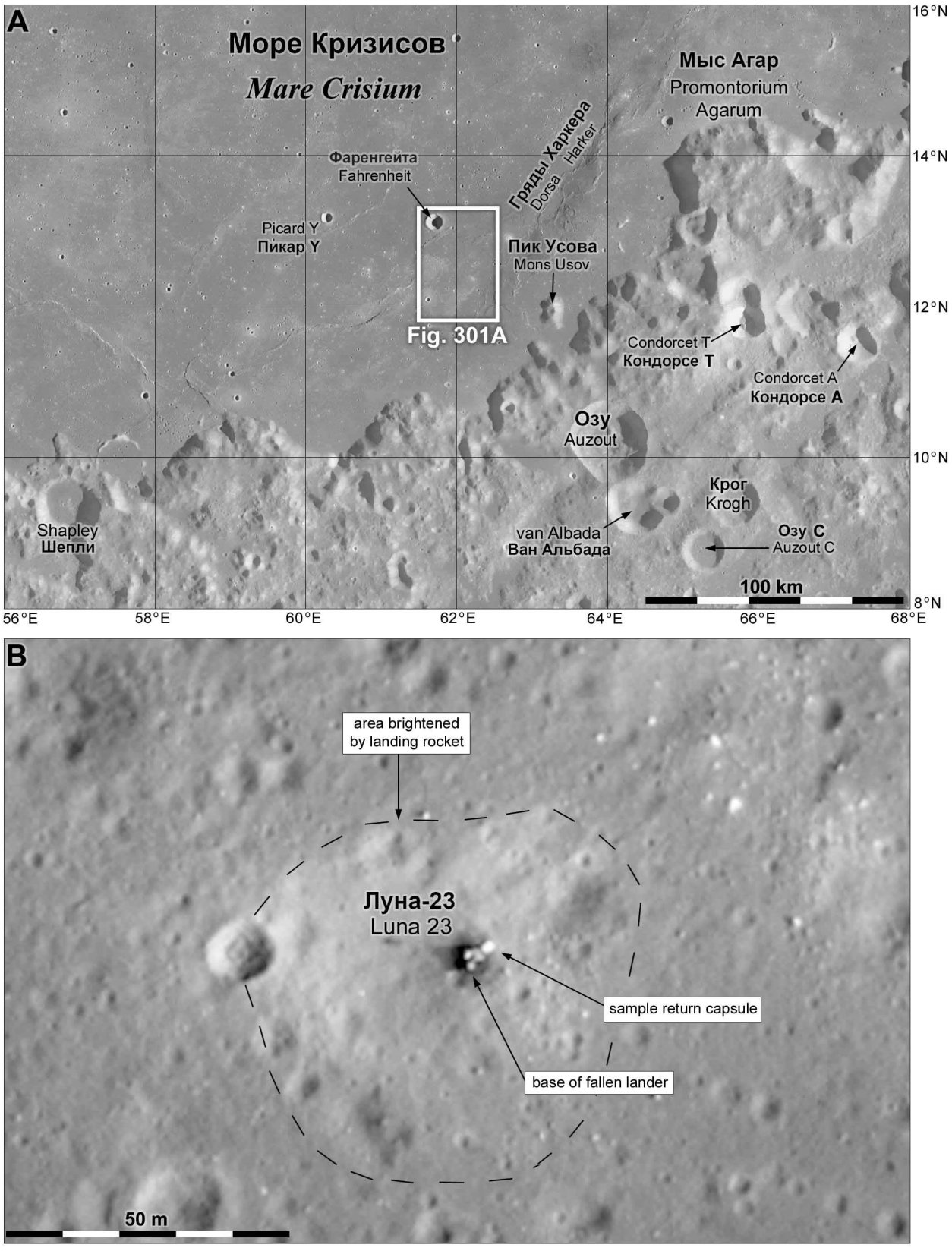

Figure 351. Luna 23. A: landing area. B: LROC NAC image M144212439R showing Luna 23.

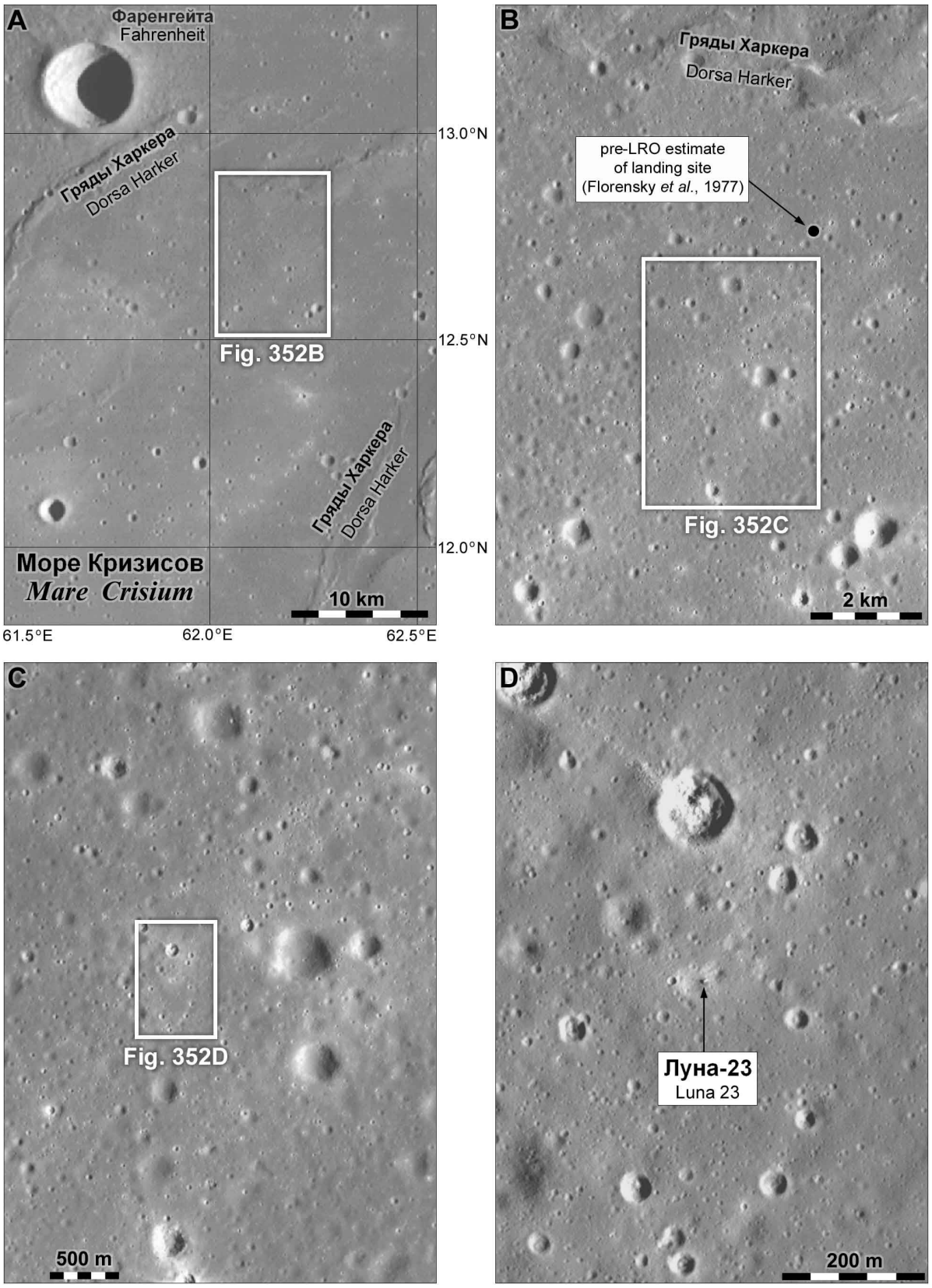

Figure 352. Luna 23 landing area.

Post-Apollo planning

The Fairchild Conference on Manned Exploration of the Moon and Planets was organized by Harrison Schmitt and Lee Silver and held at Caltech on 7-8 August 1975 to summarize the results of Apollo and look at future exploration. The proceedings have never been published, but individual talks are preserved in the archived papers of many participants. Planning for advanced post-Apollo missions had been taking place even before the first landing, including the Apollo Applications Project described earlier (*e.g*. Figure 67 and Table 20 in Chronicle part 2). Another such report was by Blahnik (1971), which mentioned a lunar orbital station and a surface base, without suggesting any location for the base. There was no money for such projects in NASA's budget and no government interest in following this path.

Blahnik, J. E., 1971. Applications of advanced spacecraft systems for lunar exploration in the 1980's and 1990's. Report no. P-38, Illinois Institute of Technology, Chicago, Illinois, June 1971.

16 October 1975: Luna 1975A

This sample return mission was launched from Baikonur with the goal of sampling Mare Crisium in place of the failed Luna 23. The spacecraft failed to reach its parking orbit due to a failure in the upper stage of the Proton launcher. The target would have been in the same region of Mare Crisium chosen for Luna 23 and Luna 24.

9 August 1976: Luna 24

Luna 24, essentially identical to Luna 23, was launched from Baikonur at 15:04 UT on 9 August 1976. It entered a temporary parking orbit and then was sent on its four day path to the Moon. A trajectory correction was made on 11 August, and on 13 August the spacecraft entered a 115 km circular orbit with a 120° inclination. On 16 August Luna 24 dropped its low point to 12 km, and on 18 August it descended to the surface. It landed safely at 02:00 UT, only 2 km from Luna 23 at 12.75° N, 62.2° E (Florensky *et al*., 1977; Butler and Morrison, 1977), but the coordinates were uncertain by several kilometers and the exact location (12.715° N, 62.213° E) was determined only by LRO imaging (Robinson, 2010; Plescia, 2012; Robinson *et al.*, 2012). The landing site was a mare plain between wrinkle ridges of the Dorsa Harker complex (Figure 354).

Soon after landing the drill was operated, descending 1.6 m into the regolith to obtain a 170 g sample, which emerged wrapped in a plastic sheath. This was wound into a spiral in a cylindrical container that was then deposited in the return capsule. After a 22.8 hour wait to ensure the capsule would fall in Soviet territory, the ascent stage lifted off on its return journey. The return took four days, with a landing 200 km SE of Surgut in western Siberia on 22 August 1976. Luna 24 basalts were about 3.3 billion years old (Wilhelms 1987), but they differed from expectations based on remote sensing. LRO images showing the lander sitting on a fresh ejecta deposit explained his discrepancy: the sample included material excavated from below the surface. Remote sensing revealed the typical surface characteristics of the surroundings but did not resolve the small, atypical ejecta deposit.

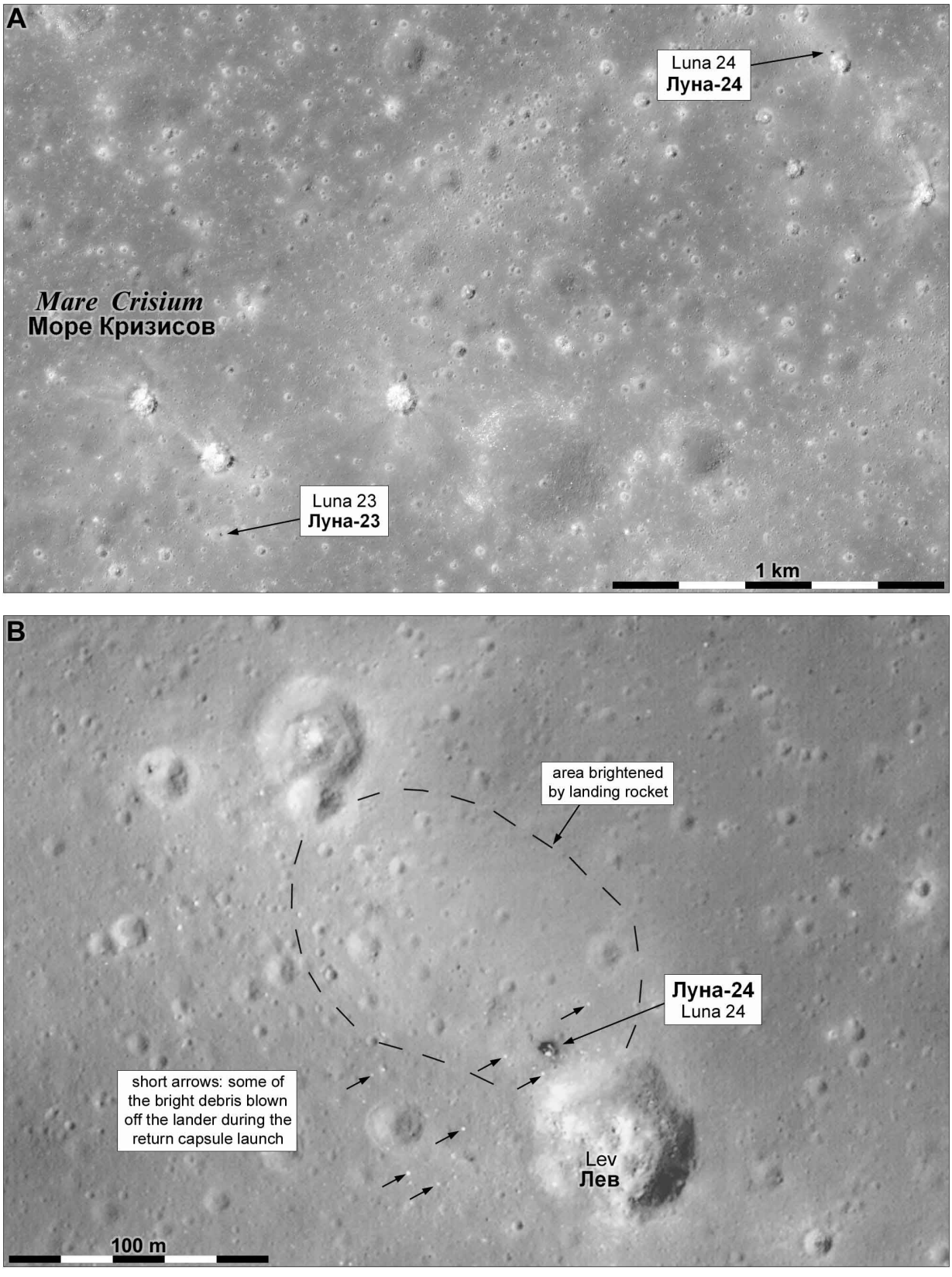

Figure 353. The Luna 24 landing area. A: Lunas 23 and 24 landed 2 km apart. B: detail of the Luna 24 landing site.

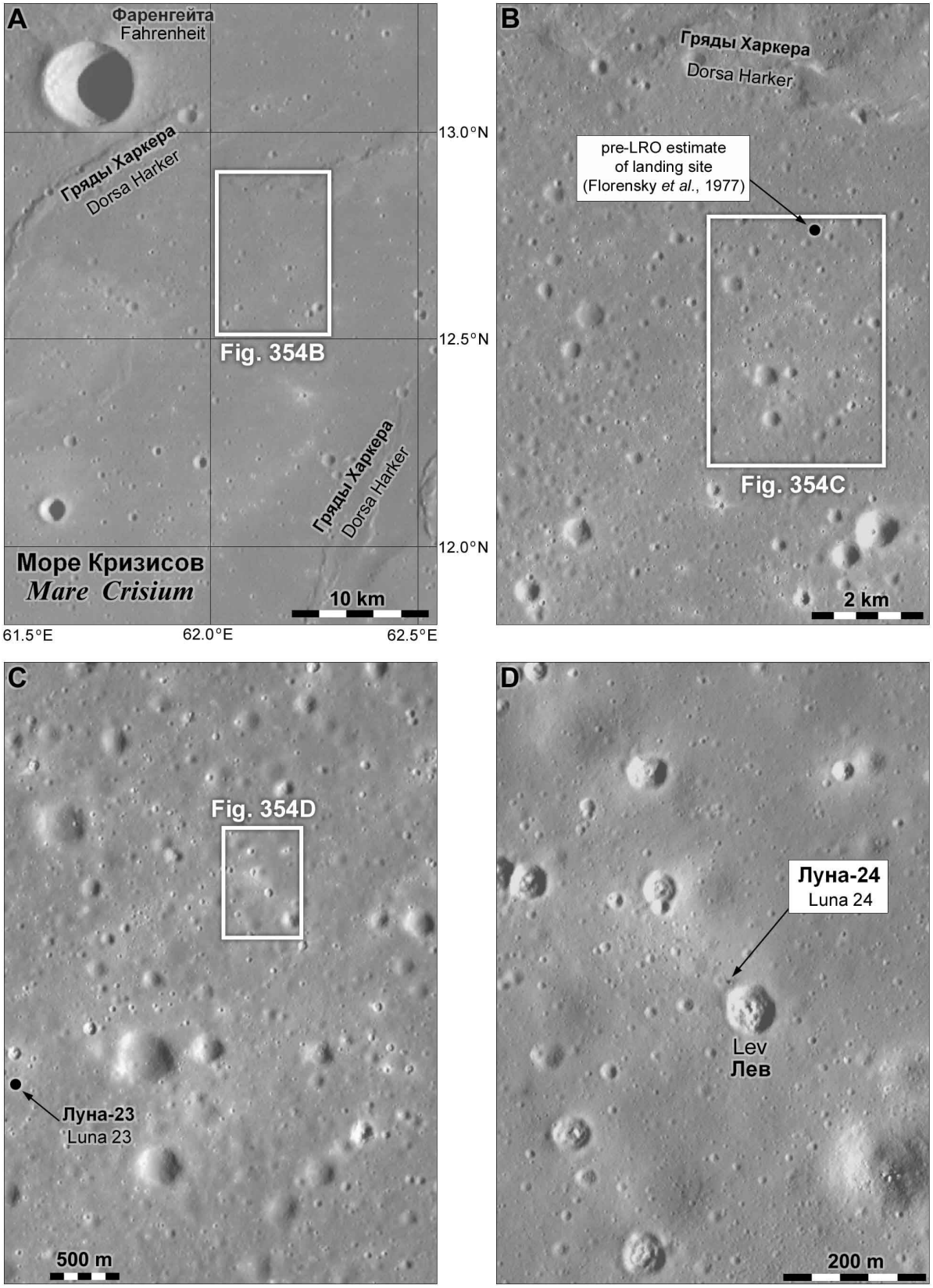

Figure 354. Luna 24 landing site.

The high resolution LRO images also showed small reflective spots around the Luna 24 lander (Figure 353B), apparently fragments of insulation or other material blown off the lander during the launch of the return capsule. The Luna 23 return capsule did not launch and no such spots occur there, but similar bright objects have been seen at Apollo 11 (Figure 148A in Chronicle part 3).

Figure 353B shows the landed spacecraft, sitting near the rim of a relatively fresh 64 m diameter impact crater now called Lev. This illustrates very clearly the danger of landing without the hazard avoidance technologies developed in the 21st Century. Figure 354 shows the area in which Luna 24 landed. The regional context of this map is shown in Figure 351A. An isolated peak 40 km southeast of the Luna 24 landing site was referred to as 'Hill 5408' (its summit elevation) in some Luna 24 literature. It is now known as Mons Usov (Figure 351A).

After LRO imaged the Luna 23 and Luna 24 landers a dispute arose among some Russian researchers regarding the identifications (Dolgopolov *et al.,* 2013). Kaydash *et al.* (2013) argued that the brightened surface area around Luna 24 is offset from the lander (Figure 353B) and used rendered images of spacecraft models and remote sensing data to suggest that the Luna 23 and 24 designations used here should be reversed. Shkuratov *et al.* (2013) added that the bright spots around Luna 24 but not Lunas 16, 20 and 23 also supported a reverse designation, making Luna 23 the unique site. Velichko *et al.* (2022) agreed with this interpretation, but the original identifications are preferred here.

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Florensky, K. P., Basilevsky, A. T., Ivanov, A. V. *et al*., 1977. Luna 24 - geologic setting of landing site and characteristics of sample core, preliminary data. *Proceedings of the 8th Lunar Science Conference*, Houston, Texas, 14-18 March 1977, v. 3. (A78-41551 18-91). New York: Pergamon Press, Inc., pp. 3257-3279.

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30 September 1977: ALSEPs turned off.

On this date the remaining instruments at the five Apollo ALSEPs were turned off, ending the data gathering phase of the Apollo program. Equipment failure had reduced the number of operating experiments considerably, with the seismometers the most important remaining instruments. Apollo 14's Central Station was suffering intermittent

shutdowns associated with temperature variations. Power was also diminishing. After two months of engineering tests the experiments were all shut down, but the transmitters remained on to provide a carrier signal for astrometric and geodetic studies at JPL and other institutions.

A summary of all ALSEP instruments is given by Lindsay (2010). Details of the shutdown were provided in a press release by Redmond (1977). Much of the ALSEP data was kept as printed or microfiche records or was lost, and as NASA began preparing for future lunar exploration in the 21st Century a significant effort was made to find ALSEP datasets and convert them to a digital format consistent with modern data archiving and to ensure their accessibility to researchers. Nagihara *et al*. (2020) describe this effort.

Lindsay, H., 2010. ALSEP. Apollo Lunar Surface Experiments Package. Essay on the Apollo Lunar Surface Journal website. Latest revision, 19 July 2010. https://www.nasa.gov/history/alsj/HamishALSEP.html

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Redmond, C., 1977. Lunar science stations to cease functioning September 30. Release no. 77-47, NASA Johnson Space Center, 1 September 1977.

Table A1. Spacecraft locations on the Moon, from this volume.			
Spacecraft	**Date of contact**	**Location**	**Event**
Apollo 17 - SIVB upper stage - LM ascent stage	11 December 1972 10 December 1972 15 December 1972	20.191° N, 30.772° E 4.167° S, 12.330° W 19.96° N, 30.50° E	Landing Impact Impact
Luna 21 - Lunokhod 2, end of drive	15 January 1973 10 May 1973	25.998° N, 30.410° E 25.827° N, 30.919° E	Landing Drive
Luna 22	unknown	unknown	Impact
Luna 23	5 November 1974	12.666° N, 62.151° E	Landing
Luna 24	18 August 1976	12.714° N, 62.213° E	Landing

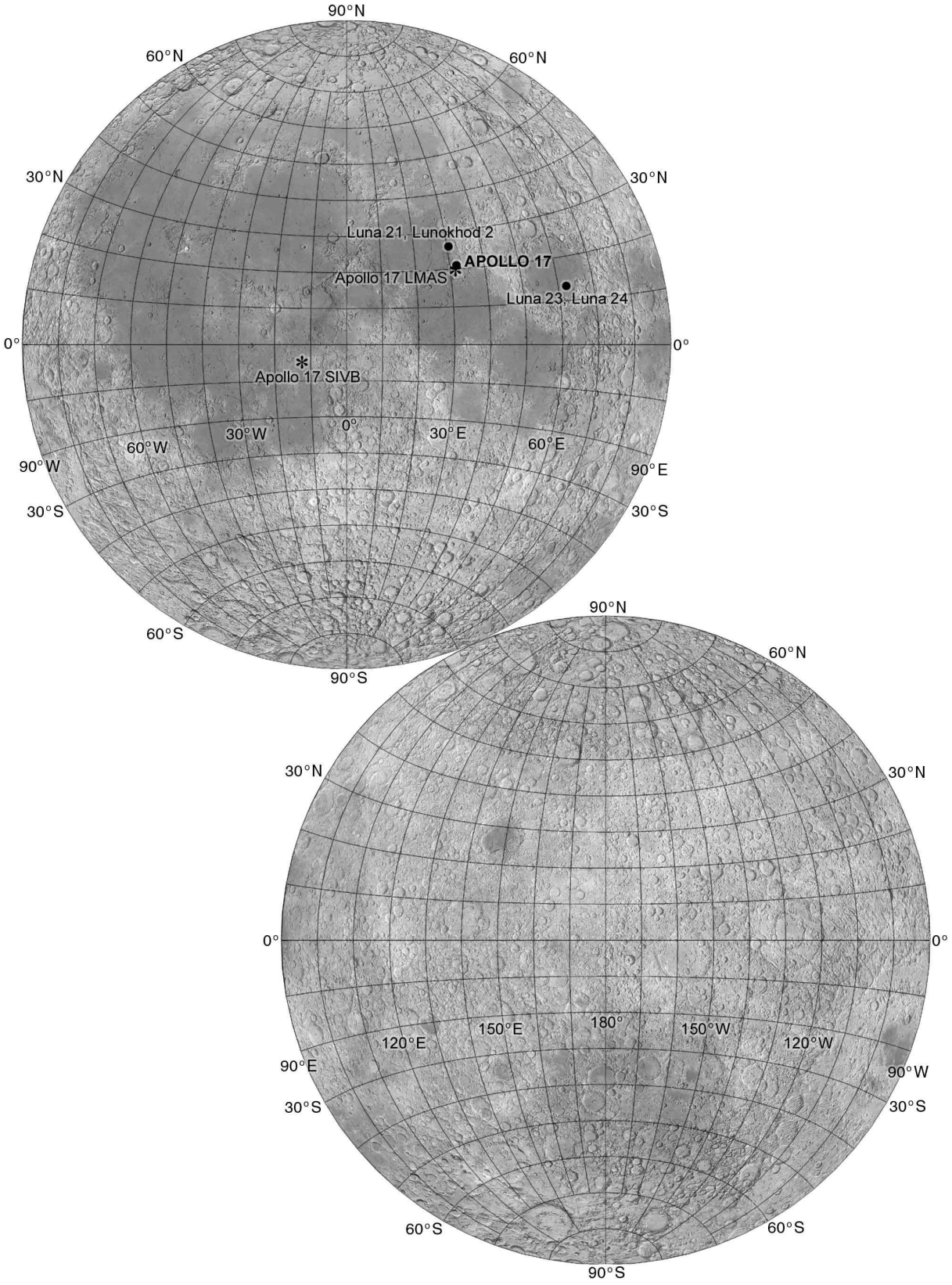

Figure A1. Lunar landings and impacts covered in this volume.